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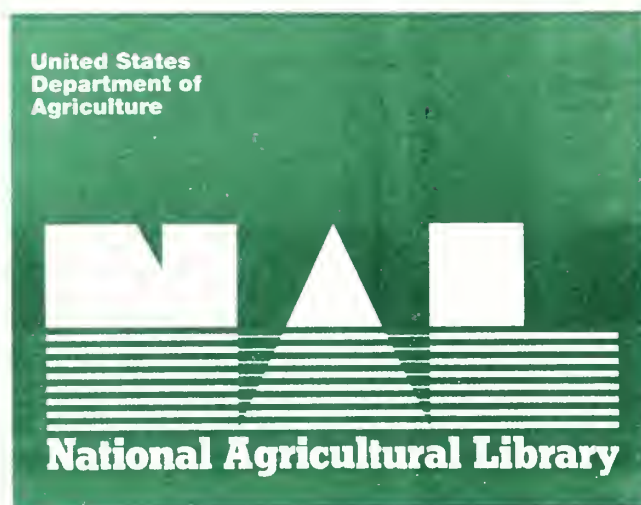
Eastside Forest Ecosystem Health Assessment

Volume III

Assessment



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This report is not intended to provide precise details on all aspects of ecosystem management. The report responds to seven questions concerning the sustainability of ecosystems in eastern Oregon and Washington, and the effects of historical management practices on sustainability of those ecosystems. This report is not a "decision document" as defined by the National Environmental Policy Act (NEPA). It does not allocate resources on public lands nor does it make recommendations to that effect. Implementation of ecosystem management on Forest Service administered lands is the responsibility of the National Forest System and Forest Service Research. Implementation is done through forest and project plans that are subject to the NEPA process of disclosing the effects of proposed actions and affording the opportunity for public comment. The information contained in this report is general in nature, rather than site specific. In making land management decisions and establishing standards and guidelines National Forest System personnel may consider this information as well as a wide variety of other information received in the course of complying with the National Environmental Policy Act and other laws. The opinions expressed by the authors of the papers in this volume do not necessarily represent the policy or position of the Department or the Forest Service.

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Eastside Forest Ecosystem Health Assessment

Volume III Assessment

April 1993

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Landscape and the Intermontane Northwest: An Environmental History¹

by

William G. Robbins and Donald W. Wolf

¹ A report for the USDA Forest Service, Pacific Northwest Research Station, Supplemental Agreement PNW 93-0304, "Historical Perspectives on Human Use of Eastside Forest Ecosystems."

The strong tendency to be concerned only with the present or near future carries with it the serious danger that . . . we shall fail to put enough weight on the long-term and secondary effects of our actions; that we shall do further damage to the very machinery of resource production that we seek to repair.

E. I. Kotok²

From time immemorial, people have been great modifiers of the ecological niches they occupy. That observation is also a proper fit for the prehistoric period in North America, where archaeological evidence shows purposeful human manipulation of the environment to be an incontestable fact.³ Indeed, the great weight of scientific evidence and hypotheses argues against the notion of the Americas as a pristine, Eden-like world where the human imprint was barely perceptible.⁴ Scholarly research in the last two decades indicates the existence of sizable prehistoric populations in the Western Hemisphere and considerable human modification to forest, riverine, prairie, and basin landscapes. Amerindian people influenced the extent and composition of forests, established and expanded grassland areas, and altered landscapes through a myriad of human devices. According to geographer William Denevan, the important question is "the form and magnitude of environmental modification rather than ... whether ... Indians lived in harmony with nature with sustainable systems of resource management."⁵

Although it is generally acknowledged that human environmental influences in prehistoric North America were considerable, it is now widely understood that the Columbian encounter triggered vast biological and technological changes with worldwide repercussions. After the event of 1492, a developing global network of economic and biological exchanges emerged whose "international energy flows," according to Karl Butzer, favored the emerging centers of the industrial revolution; as the industrializing sector expanded its technological reach, forces were set in motion that introduced immense social and environmental changes worldwide.⁶ To point out the obvious, succeeding modes of production—hunting/fishing/gathering, peasant agriculture, and the industrial/postindustrial mode—have increased the extent and scope of the human influence in the natural world.⁷

Both natural and cultural processes have been involved in shaping the environments about us. But culture became a factor in environmental change only with the emergence of modern humans during the mid-point of the last glacial period, say 40,000 B.P. (before the present), when they were in the process of colonizing most of the earth. For thousands of years, however, population numbers and technological practices limited the human imprint on global change. With the exception of a possible role in Pleistocene extinctions, therefore, human-induced environmental change on a broad scale was limited. But with warming conditions and the northward advance of forest ecosystems and plant life during the early

²E. I. Kotok, "The Ecological Approach to Conservation Programs," in Renewable Natural Resources, Section IV (circa 1950), 472 (copy in library, Blue Mountain Natural Resources Institute, La Grande, Oregon).

³For a select number of scholars who argue this point, see Carl O. Sauer, "Man in the Ecology of Tropical America," Proceedings of the Ninth Pacific Science Congress 20 (1957), 104-10; Sauer, "Man's Dominance by Use of Fire," Geoscience and Man 10 (1975), 1-13; William Cronon, Changes in the Land: Indians, Colonists, and the Ecology of New England (New York: Hill and Wang, 1983); and Richard White, Land Use, Environment, and Social Change: The Shaping of Island County, Washington (Seattle: University of Washington Press, 1980).

⁴For an excellent review, see Karl W. Butzer, "The Americas Before and After 1492: An Introduction to Current Geographical Research," Annals of the Association of American Geographers 82, 3 (1992), 345-366.

⁵William M. Denevan, "The Pristine Myth: The Landscape of the Americas in 1492," Annals of the Association of American Geographers 82, 3 (1992), 370.

⁶Butzer, "The Americas Before and After 1492," 346.

⁷Neil Roberts, The Holocene: An Environmental History (New York: Basil Blackwell, 1989), 5.

Holocene (10,000 to 5,000 B.P.), the human impress on the natural world became much more noticeable. The more favorable climatic conditions expanded the range of ecological niches suitable to human habitation and allowed for people to manipulate plant and animal species to their advantage. But more than anything else, it was the advent of Neolithic agriculture that accelerated the human role in environmental change in many parts of the world.⁸

Several archaeological finds, including one at Oregon's Fort Rock Cave (13,000 B.P.) on the periphery of the Great Basin,⁹ indicate that humans first entered the greater Pacific Northwest¹⁰ during the late Pleistocene, when glaciers still covered much of the mountainous country of the interior. Before the dramatic warming of the climate between 11,000 and 9,000 B.P., now-extinct animals—the giant ground sloth, the giant bison, the camel, and the horse—were still present in North America. Those species intermingled with present-day animals—antelope, deer, mountain sheep, and a variety of bird life.¹¹ For reasons that are still subject to great controversy, several of those late Pleistocene mammals became extinct; whether the human presence in North America (and in the Pacific Northwest) is responsible for those extinctions remains an open question.¹²

As the great glaciers of the late Pleistocene receded, they unleashed a series of catastrophic floods through the upper-Columbia River drainage when Lake Missoula periodically burst through its dam of glacial ice. The scouring effects of that huge volume of water created the channeled scablands of eastern Washington, including the famous Grand Coulee. The most recent of those floods probably occurred some time after 13,000 B.P. With the recession of the glaciers, spruce, fir, and other conifers appeared over broad areas of the interior country, and when the climate began to warm after 11,000 B.P., the conifers themselves receded to higher elevations.¹³

With the onset of the modern era (about 500 B.P.), human-manipulated agricultural ecosystems had replaced natural ones in many parts of the world.¹⁴ But economic, environmental, and ecological changes taking place elsewhere were delayed in the Pacific Northwest. Until the very recent past, the region was beyond the reach—or at best on the periphery—of the immense market-induced ecological exchanges that were taking place in the post-Columbian world. Euro-American penetration and conquest on this far edge of North America, therefore, has been of very recent duration, extending back little more than two centuries. Indeed, what is striking about the region is the very recent and *very* rapid pace of human-induced environmental disturbance over *very* extensive areas in a very brief span of time.¹⁵

⁸*ibid.*, 57-113.

⁹For a brief account of the Fort Rock and other Northwest archaeology excavations, see L. S. Cressman, *The Sandal and the Cave: The Indians of Oregon* (1962; Corvallis: Oregon State University Press, 1981).

¹⁰This reference is to the physiographic region that embraces the present states of Washington, Oregon, and Idaho, northern California and Nevada, western Montana, and southern British Columbia. The greater Columbia River system also provides a definitive outline for the region.

¹¹C. Melvin Aikens, *Archaeology of Oregon* (Portland: Oregon State Office, U. S. Department of the Interior, Bureau of Land Management, 1986), 9-10.

¹²Roberts, *The Holocene*, 67; Donald K. Grayson, "Pleistocene Avifaunas and the Overkill Hypothesis," *Science* 195 (1977), 691-93; and Paul S. Martin, "Pleistocene Overkill," *Science* 179 (1973), 969.

¹³Aikens, *Archaeology of Oregon*, 41-42; and Hunn, *Nch'i-wana*, 19-21.

¹⁴Roberts, *The Holocene*, 122.

¹⁵Carlos Schwantes argues that "geographical isolation fundamentally shaped the course of Pacific Northwest history." Geography conspired to keep the Northwest "beyond the reach of Europe and the rest of North America" and thereby "contributed to a pronounced time lag in its historical development." See Schwantes, *The Pacific Northwest: An Interpretive History* (Lincoln: University of Nebraska Press, 1989), 19.

For the interior Northwest, the hunting-gathering way of life remained dominant until Europeans began to impose a new set of cultural arrangements on the landscape. The Pacific Northwest was an anomaly in one other respect: Neolithic agricultural practices were absent during the Indian period of domination. "Therefore," according to fisheries and wildlife scientist Dean Shinn, "we are still relatively close to the early history of the region, and to the events which caused environmental change there."¹⁶

That historical configuration of events and circumstances provides exceptional opportunities for studying precontact landscapes, for learning about ecological conditions at the onset of large-scale Euro-American migration, and for placing the human-induced changes that have taken place in the industrial age in a broader perspective. In brief, the telescoping of the postcontact history of the region into such a brief span of time makes it possible to discern—through conventional historical records (journals, diaries, government surveys, and travel accounts)—much about ecological conditions at the time of the entry of Euro-Americans. That scholars are increasingly turning to pollen and soil records and traditional archaeological evidence further enriches the potential for building a realistic profile of landscapes and environments.

Once the postglacial regime established itself—with the exception of the cataclysmic explosion of Mount Mazama (about 6,000 B.P.)—environmental conditions in the intermontane Northwest remained *relatively*¹⁷ stable for at least 10,000 years. For the Plateau culture area of the interior Northwest, the archaeological record indicates a consensus of sorts: cultural and social changes were modest until the historic period, with subsistence patterns centered largely on terrestrial and riverine environments. Only the northward spread of Spanish horses in the early 18th century, the entry of the market-oriented fur trade in the early 19th century, and ravages of the exotic epidemic diseases that followed disrupted that stability.¹⁸

But relative social and cultural stability does not imply the absence of native influence in the natural world. Indeed, extensive archaeological and other historical evidence suggests quite the opposite. Native Americans in the Pacific Northwest inhabited a humanized landscape—ecosystems that were purposefully modified to meet their subsistence needs. Richard White argues that native people on Puget Sound's Whidbey Island used fire as a tool to enhance the growing of bracken and camas, staple vegetables in their diet. "Rather than being major Indian food sources because they dominated the prairies," he concludes, "camas and bracken more likely dominated the prairies because they were major Indian food sources."¹⁹ There is abundant evidence to indicate equally human-influenced landscapes elsewhere in the Pacific Northwest.

¹⁶Dean A. Shinn, "Historical Perspectives on Range Burning in the Inland Pacific Northwest," *Journal of Range Management* 33 (November 1980), 418-19. For the absence of Neolithic agriculture in the Pacific Northwest, see Butzer, "The Americas Before and After 1492," 348; White, *Land Use, Environment, and Social Change*, 14-34; Philip Drucker, *Indians of the Northwest Coast* (Garden City, New York: Natural History Press, 1955), 35-55; and Cressman, *Sandal and the Cave*, 40-54. For a discussion of the food-gathering practices of the Palouse Indians, see Clifford E. Trafzer and Richard D. Scheuerman, *Renegade Tribe: The Palouse Indians and the Invasion of the Indian Pacific Northwest* (Pullman: Washington State University Press, 1986), 7-9.

¹⁷That is not to deny what the anthropologist Eugene Hunn calls "the biogeographical consequences of climatic change." But, he points out, changes in climatic patterns required adjustments in hunting and gathering strategies rather than dramatic economic and social change. See Hunn, *Nch'i-Wana "The Big River": Mid-Columbia Indians and Their Land* (Seattle: University of Washington Press, 1990), 19. Richard White makes the same argument for the native people of Puget Sound, who had been in a "relatively stable and productive environment" for centuries before the arrival of white settlers. See White, "The Altered Landscape: Social Change and the Land in the Pacific Northwest," in *Regionalism and the Pacific Northwest*, William G. Robbins, Robert J. Frank, and Richard E. Ross, eds. (Corvallis: Oregon State University Press, 1983), 114-115.

¹⁸Hunn, *Nch'i-wana*, 21; and Hunn, "The Plateau," in *The First Oregonians*, Carolyn M. Buan and Richard Lewis, eds. (Portland: Oregon Council for the Humanities, 1991), 14.

¹⁹White, *Land Use, Environment, and Social Change*, 21; and White, "The Altered Landscape," 111. William Cronon illustrates a similar case for southern New England where the Indian use of fire may have been even more frequent and pronounced. The area's forests were park-like with intermittent openings, "not because the trees naturally grew thus, but because the Indians preferred them so." See Cronon, *Changes in the Land: Indians, Colonists, and the Ecology of New England* (New York: Hill and Wang, 1983), 49.

Native-modified landscapes through the use of fire extended well beyond the Puget and Willamette lowlands to the eastern slopes of the Cascade Range, where Indians used fire as an effective tool to enhance the production of a variety of foodstuffs, including nutritious herbs and shrubs, black mountain huckleberry, and its near relatives, blueberry and grouseberry. Those fire-created niches also attracted browsing animals like deer and elk, sources of protein for the Indian diet.²⁰ The widespread practice of burning created an artificial forest environment of open glades and park-like settings, a descriptive refrain that runs through virtually all of the 19th century travel and survey literature.

Except for the extremely arid regions of North America, the historian Stephen Pyne contends that grassland environments were also the result of the Indian's calculated and routine use of fire. From the coastal plain of Massachusetts southward to Florida and westward to Texas, from California's great Central Valley to Oregon's Willamette Valley, grasslands flourished as a consequence of Indian incendiary activity.²¹ Native influences in modifying grassland environments in the "Great Columbia Plain"²² region of eastern Washington and across the high-desert country of eastern Oregon is also too obvious to ignore.

Some evidence indicates that early Pleistocene hunters in the Northwest used burning thousands of years ago, and references to fires and burned landscapes run everywhere through the early literature of the region. Although historical sources do not reveal with any precision the ratio between human and naturally caused fires in the interior Pacific Northwest before large-scale white settlement, evidence suggests that Indian incendiarism was a significant factor in the burning of both grassland and forest. For desert ecosystems, Lee Eddleman contends, "human caused fires were of greater consequence." Other writers agree: fire "was a natural component of the native ecosystem."²³ Early 19th century travel accounts mention fire with such regularity as to create a mental picture of a ravaged, charred, ruined land.

As with much of the early literature of the Pacific Northwest, the journals of Lewis and Clark revealed the complexities of Indian environmental influence, especially the important role of fire to the horse-mounted hunter-gatherers of the interior country. On the return trip upriver in the spring of 1806, Meriwether Lewis reported the plains of the Columbia covered with a "rich verdure of grass and herbs from four to nine inches high." As the party drew closer to the Walla Walla River, the journal entries refer to a unique set of observations: the absence of firewood; the Indian use of shrubs for fuel; an abundance of roots for human consumption; and favorable assessments of grass for horses. Writing some distance up the Walla Walla River, William Clark remarked that "great portions of these bottoms has been latterly burnt which has entirely destroyed (sic) the timbered growth."²⁴

The native people readily fired arid landscapes just as they did the Willamette and Puget lowlands to enhance hunting and the gathering of roots and berries. Hudson's Bay Company operative Peter Skene Ogden, leading a trapping party through the upper Crooked River and into the Harney Basin in 1826 and 1827, repeatedly referred to a country "overrun by fire," with the finger of guilt pointed to what he deemed were native culprits. But Ogden's greatest disappointment about those summer conflagrations centered on the widespread destruction of beaver habitat (and beaver):

²⁰Hunn, "Nch'i-wana "The Big River," 130-131.

²¹Stephen J. Pyne, *Fire in America: A Cultural History of Wildland and Rural Fire* (Princeton: Princeton University Press, 1982), 84-85. In Oregon's Willamette Valley native people used fire in a substantial way to dramatically alter the landscape for their own purposes. See Peter G. Boag, *Environment and Experience: Settlement Culture in Nineteenth-Century Oregon* (Berkeley: University of California Press, 1992), 12-15.

²²This is the title of Donald Meinig's *The Great Columbia Plain: A Historical Geography, 1805-1910* (Seattle: University of Washington Press, 1968), still the best book of its kind for the Pacific Northwest.

²³Shinn, "Historical Perspectives on Range Burning in the Inland Pacific Northwest," 415-417; Lee Eddleman, "Oregon's High Desert—Legacy for Today," in *Oregon's High Desert: The Last 100 Years*, Special Report 841 (June 1989), Agricultural Experiment Station, Oregon State University, Corvallis, Oregon, and USDA Agricultural Research Service, 2; and J. B. Kauffman and D.B. Sapsis, "The Natural Role of Fire in Oregon's High Desert," in *ibid.*, 15.

²⁴Thwaites, *Original Journals of the Lewis and Clark Expedition*, vol. 3, P. 345-346.

Many small streams have been discovered in the mountains and were not long since well supplied with beaver but unfortunately the Natives have destroyed them all and probably by the aid of fire which is certainly a most destructive mode of exterminating them for scarcely ever one escapes particularly when the streams are not wide, and from what I have seen in this my last years travels I will venture to assert without exaggeration the Natives have destroyed and principally by fire upwards of sixty thousand beavers and of this number not a Hundred have reached any establishment but all have been lost.²⁵

As the explorer/fur-trader extraordinaire, Ogden saw the regional landscape through a sharply different cultural lens from that of the Paiutes of eastern Oregon. The Indian habit of burning for **Indian purposes**, in his view, was irrational because it led to the destruction of beaver, an animal with a commodity value in distant markets.²⁶

John Kirk Townsend, Philadelphia-based naturalist and traveler on the Oregon Trail, provides one of the most vivid accounts of Indian burning practices in the Columbia River country. When the party camped about 15 miles below the mouth of the Umatilla River on the evening of September 3, 1835, Townsend reported that Indians had “fired the prairie” on the opposite side of the river, thereby brilliantly lighting the night sky:

Here I am sitting cross legged on the ground, scribbling by the light of the vast conflagration with as much ease as if I had a ton of oil burning by my side; but my eyes are every moment involuntarily wandering from the paper before me, to contemplate and admire the grandure (sic) of the distant scene. The very heavens themselves appear ignited, and the fragments of ashes and burning grass-blades, ascending and careering about through the glowing firmament, look like brilliant and glorious birds let loose to roam and revel amidst this splendid scene.

Standing on a hilltop at the mouth of the Walla Walla River the following spring, the Reverend Samuel Parker described a landscape “covered with the fresh green of spring vegetation.” Just a few miles to the north at the juncture of the Snake River he remarked again about “the fresh verdure, which is springing up, luxuriantly, at this early season.”²⁷

Looking toward the Columbia River from the western slopes of the Blue Mountains in mid-October 1840, United States Army reconnaissance officer John C. Fremont reported that “smoky and unfavorable” weather conditions obstructed “far views with the glass.” But before descending to the Walla Walla River,

²⁵M. A. Davies, ed., *Peter Skene Ogden's Snake Country Journals, 1826-27* (London: Hudson's Bay Record Society, 1961), 7, 9, 19, 118, and 126-127.

²⁶Explorer and discovery accounts of the Americas dating from the time of Columbus, according to Richard White, appraised objects in the physical environment in terms of their value as commodities. See White, “Discovering Nature in North America,” *Journal of American History* 79 (December 1992), 879-880.

²⁷John Kirk Townsend, *Narrative Journey across the Rocky Mountains* (1839; Lincoln: University of Nebraska Press, 1978), 246; and Samuel Parker, *Journal of an Exploring Tour Beyond the Rocky Mountains* (1838; Minneapolis: Ross and Haines, 1967), 272 and 274. Passing up the Columbia River on April 17, 1806, Meriwether Lewis reported “a rich verdure of grass and herbs from four to nine inches high and exhibits a beautiful seen (sic) particularly pleasing after having been so long imprisoned in the mountains and those impenetrably thick forests of the seacoast.” See Reuben Gold Thwaites, ed., *Original Journals of the Lewis and Clark Expedition, 1804-1806* (New York: Antiquarian Press Ltd., 1959), vol. 3, p. 286. In the same entry, Lewis noted that the Indians burned shrubs because of the absence of firewood, that grasses provided excellent grazing for horses, and that burned-over areas were superb grounds for gathering roots.

Fremont observed what he deemed to be the salutary aftereffects of burning: “the grass very green and good; the old grass having been burnt off early in the autumn.” Although both culture and nature were responsible for shaping the environment of the intermontane region, the preponderance of evidence suggests that culture was a major cause of incendiarism.²⁸

Although the bulk of this discussion has focused on the Indian use of fire in arid landscapes, culture evidently played a major role in the ecology of the intermontane forests as well. For the greater Blue Mountains area, early travel accounts—many of them Oregon Trail narratives—provide copious testimony to the ecologically intrusive presence of Native Americans throughout the region. Stories of fire and ash are strewn along the section of the trail from the juncture of the Boise and Snake rivers to the Columbia. After leaving the Grande Ronde Valley in a northwesterly direction through the Blue Mountains in late August of 1834, John Kirk Townsend remarked about the stately pine trees with an undergrowth of “service bushes and other shrubs.” What most offended Townsend, however, was the burned grass and trees “blasted by the ravaging fires of the Indians. These fires are yet smoldering, and the smoke from them effectually prevents our viewing the surrounding country.”²⁹

The ubiquitous and controversial Captain Benjamin Bonneville crisscrossed the Snake River/Blue Mountain country in 1834 and later made his notes available to Washington Irving, who wrote an account of Bonneville’s travels. According to Irving’s version, during the summer months the captain witnessed “the season of setting fires to the prairie,” with fire and smoke virtually everywhere. Bonneville’s troop subsequently spent two weeks camped in the Grande Ronde Valley because fires in the surrounding hills blocked egress from the area.³⁰

Passing through the high country dividing the Powder River and Grande Ronde valleys in August 1835, the missionary Jason Lee described a landscape “covered with a heavy growth of pitch pine, very large, tall, and beautiful.” The only distracting feature to the Methodist was the evidence of fire that “had recently been making its destructive ravages over the whole mountain.” After ascending the Blue Mountains and traveling across the summit, Lee reported the party’s vision obscured “by smoke, which was [so] dense that we could discern objects only a few yards.” Four years later, Thomas Jefferson Farnham followed the west bank of the Snake River and then moved into the hills along a small stream where Indians had recently burned the countryside. The following day, Farnham described an atmosphere filled with smoke “as in Indian summer-time in the highlands of New England.”³¹

By the time the large emigrant train of 1843 was enroute to the Willamette Valley, newcomers traveling through the interior Northwest were becoming familiar with late-summer Indian fires. The trapper James Clyman, who accompanied an 1844 emigrant party to Fort Boise and then pressed on ahead to Oregon, observed “verry Smoky” weather in the Powder River Valley and even worse conditions in the Grande Ronde Valley where, “Indians as is their habit . . . set fire to the grass.” Passing northward from the

²⁸Donald Jackson and Mary Lee Spence, eds., *The Expeditions of John Charles Fremont*, vol. 1 (Chicago: University of Chicago Press, 1970), 550-551; and Lee Eddleman, “Oregon’s High Desert—Legacy For Today,” 2. Except for these early first-hand accounts, no body of solid “data” exists to prove the case one way or the other.

²⁹Townsend, *Narrative Journey Across the Rocky Mountains*, 163.

³⁰Washington Irving, *The Adventures of Captain Bonneville, U.S.A., in the Rocky Mountains and the Far West: Digested from His Journal, and Illustrated from Various Other Sources* (1837; Norman: University of Oklahoma Press, 1961), 339-341.

³¹Archer Butler Hulbert and Dorothy Printup Hulbert, eds., *The Oregon Crusade: Across Land & Sea to Oregon* (Denver: Colorado College, 1935), 178; and Farnham, *An 1839 Wagon Train Journal*, 73.

Powder River, Clyman's group "nearly suffocated with smoke & dust," and upon descending into the Grande Ronde Valley, they witnessed "the whole mountains which surround this vally (sic) completely enveloped in fire and Smoke."³²

Much of the scientific and technical literature on the influence of fire in shaping ecosystems in the Pacific Northwest has an ironic twist. Virtually all writers recognize that Indians used fire as a tool to fashion grassland and forest environments for a variety of purposes. But once acknowledging that fact, those same writers move on to discussions of "fire and its role in the pristine environment" as if native people had no existence, except as part of nature itself. One authority on fire history, while conceding "significant Indian influence," refers to nineteenth-century forests as "unmanaged" and "natural" environments. In other words, before the advent of modern forest management, Northwest woodlands were neither humanized nor culturally proscribed places. As Richard White has observed: "perhaps the most important decision Europeans made about American nature . . . was that they were not part of it, but Indians were." Moreover, he argues, even when the newcomers encountered human-influenced ecosystems, they "tended to deny that Indians could have created them."³³

By the early 19th century, native people in the interior Northwest had acquired sizable numbers of horses, with some tribes—the Yakima, Cayuse, and Nez Perce—possessing especially large herds. The diffusion of horses across western North America originated in the Spanish colonies in what is New Mexico. When the Pueblo Indians revolted in 1680 and drove the Spanish out of the Rio Grande country, they liberated the Spaniards' horses, which quickly spread northward along both sides of the Rocky Mountains. Horses were passed along the western slope from the Utes to the Shoshones on the upper Snake River, to the Flatheads by 1720, and most likely to the Nez Perce and Cayuse in the 1730s.³⁴ That the acquisition of horses dramatically increased Indian mobility (and thereby Indian economic and social life) is well known; what is more difficult to discern is the extent and magnitude of ecological change that should be attributed to the horse. Until the large-scale settler movement to the Northwest in the 1840s, the horse represented, along with fire, an Indian-mediated presence in the landscape.

The early and numerous journal references to the abundance of Indian horses indicates that the human influence in shaping intermontane ecosystems assumed forms other than fire. Struggling through the snow-clad Blue Mountains to the north of the Grande Ronde Valley in the winter of 1811-1812, the Astorian Wilson Price Hunt observed on every side of their route "horse-trails used by Indians." When party members reached the Umatilla River, they visited an Indian camp of 34 lodges with an estimated

³²James Clyman, *Journal of a Mountain Man* (Missoula: Mountain Press Publishing Company, 1984). The expedition led by Captain John C. Fremont through the Snake River, Blue Mountains, and Columbia River area about two weeks behind the Great Migration of 1843 made reference to "recently burnt and blackened" surroundings, "smoky and unfavorable" weather, and grasslands "having been burnt off early in the autumn." See Jackson and Spence, eds., *The Expeditions of John Charles Fremont*, vol. 1, p. 542, 550-551.

³³James A. Young and B. Abbott Sparks, *Cattle in the Cold Desert* (Logan: Utah State University Press, 1985), 27; James K. Agee, "The Historical Role of Fire in Pacific Northwest Forests," in *Natural and Proscribed Fire in Pacific Northwest Forests*, John D. Walstad, Steven R. Radosevich, and David V. Sandberg, eds. (Corvallis: Oregon State University Press, 1990), 26-27; and White, "Discovering Nature in North America," 882. One Forest Service employee recalled that in 1909 the Siskiyou forest "was largely as the Indians had left it. It had lots of game in the mountains and fish in the rivers," indications of a relatively pristine environment. But then the writer proceeded to tell of using old Indian trails through areas where "practically all the forest had been burned over." See Henry E. Haefner to Gifford Pinchot, Gifford Pinchot Papers, Series B, Container 986, Manuscript Division, Library of Congress.

³⁴Francis Haines, "The Northward Spread of Horses Among the Plains Indians," *American Anthropologist* 40 (1938), 434-35; J. Orin Oliphant, "History of the Livestock Industry in the Pacific Northwest," *Oregon Historical Quarterly* 49 (1948), 13; and Hunn, Nch'i-wana "The Big River," 22-26. For many Indian people, according to Eugene Hunn, horses continue to symbolize the "old" way of life: "Several hundred run wild over the Yakima Reservation foothills. The tribe protects them against the urgings of stockmen who see wild horses as economic competitors" (p. 26).

2000 horses. Moreover, villagers with copper kettles and pots about their lodges and dressed in robes of bison and buckskin leggings indicated extensive travel by horseback or trade with distant peoples. Passing down the arid stretch of the Columbia River between the Umatilla and the Great Falls (Celilo Falls) in September of 1834, John Kirk Townsend reported seeing "large bands of Indian horses." Those "beautiful animals . . . almost as wild as deer" and marked with "strange hieroglyphic looking characters" to indicate ownership."³⁵

Five years later, Thomas Jefferson Farnham met a Cayuse family in the Blue Mountains, returning from a buffalo hunt to the east. The man and woman and their two children had seventeen horses in tow, "splendid animals," Farnham noted, "as large as the best horses of the States, well knit, deep and wide in the shoulders." When he reached the south bank of the Columbia River, he noticed that "groups of Indian horses occasionally appeared." And at the onset of the settler movement to the Willamette Valley in the early 1840s, the inveterate preacher-traveler Samuel Parker recorded in his journal that he saw several "bands of Indian horses" as well as deer and antelope.³⁶

When his reconnaissance troop reached the Walla Walla River in October of 1843, John C. Fremont observed "several hundred horses grazing on the hills, . . . and as we advanced on the road we met other bands, which the Indians were driving out to pasture also on the hills." A month later, journeying through the eastern slope of the Cascade Range, he reported a village of Nez Perce "who appeared to be coming from the mountains, and had with them fine bands of horses." Fellow army officer Major Osborne Cross, on the Umatilla River in September 1849, witnessed everywhere "large droves of horses, . . . stout, well built, and very muscular." And a decade later in the Grande Ronde Valley George Belshaw observed "quantities of Indians and Poneys" (sic) in "this butiful valey" (sic).³⁷

That Parker and other observers lumped horses, deer, and antelope as part of the natural world points to another problem in distinguishing between the natural and unnatural. Horses, of course, were unlike deer and antelope: they were **unnatural** to the region; they were Indian cultural adaptations of the relatively recent past; they were large grazing ungulates; and, as an alien introduction, they **unquestionably** represented a new and intrusive agent in their adopted environments.³⁸ Because human agency was responsible for the introduction of horses, Indian use of the animals should be considered another culturally engendered force in shaping the landscape of the Indian Northwest.

³⁵Wilson Price Hunt's *Diary of his Overland Trip Westward to Astoria in 1811-12*, in *The Discovery of the Oregon Trail: Robert Stuart's Narratives*, Philip Ashton Rollins, ed. (New York: Charles Scribner's Sons, 1935), 301-302; and Townsend, *Narrative Journey Across the Rocky Mountains*, 283. Nearly every Oregon Trail travel account mentions the great number of Indian horses on both sides of the Blue Mountains. Writing from a camp on the Walla Walla river in 1843, James Nesmith mentioned great difficulty in the morning hunting down their cattle and horses, "the later (sic) having wandered off and the Indian horses being so numerous made it difficult for us to find our own." See Nesmith Ankeny, *The West as I Knew It* (Lewiston: R. G. Bailey, 1953), 27. Early booster publications also mentioned that Indians raised "horses in vast numbers, and of a very superior quality," perhaps as an enticement to spur further emigration. See Lansford W. Hastings, *The Emigrants' Guide to Oregon and California* (1845; Princeton: Princeton University Press, 1932), 46.

³⁶Farnham, *An 1839 Wagon Train Journal*, 74-75; and Parker, *Journal of an Exploring Tour Beyond the Rocky Mountains*, 281.

³⁷Jackson and Spence, eds., *The Expeditions of John Charles Fremont*, vol. 1, p. 551 and 584; Raymond W. Settle, ed., *The March of the Mounted Riflemen as Recorded in the Journals of Major Osborne Cross and George Gibbs and the Official Report of Colonel Loring* (Glendale, CA: Arthur H. Clark Co, 1940), 229; George Belshaw, *Diary of the Oregon Trail, 1853* (Eugene: Lane County Historical Society, 1960), n.p. John W. Evans, who has compiled an excellent volume of the early travel accounts on this section of the Oregon Trail, contends that Indians fired the prairie in the late summer to ensure "an abundance of new grass for their horse herds." See Evans, *Powerful Rocky*, 29n.

³⁸Although the literature on Indian horse herds as agents of ecological change is not large, a growing body of evidence suggests that the ecological influence of the rapid spread of horses in western North America was considerable. See Richard White, *The Roots of Dependency: Subsistence, Environment, and Social Change Among the Choctaws, Pawnees, and Navajos* (Lincoln: University of Nebraska Press, 1983), 100, and 247-248; and Dan Flores, "Bison Ecology and Bison Diplomacy: The Southern Plains from 1800 to 1850," *Journal of American History* 78 (1991), 481.

After the United States established sovereignty over the country south of the 49th parallel in 1846, the government undertook a series of boundary, military road, and railroad surveys, with many of the investigations centering on the Cascades. Those inquiries provide further evidence of ecosystems heavily influenced by human activity. The reports of the Northwest Boundary Survey Commission offer an excellent cross-sectional description of the transition in forest types on the western and eastern slopes of the Cascade Range. On the western side, the timber was dense, "being a heavy growth of pine and fir that in many places stands over a fallen forest not yet decayed." But east of the summit, the commission noted "the timber becomes more open, and survey operations less difficult."³⁹

At the far eastern extreme of Washington Territory, a reconnaissance group under the command of Captain John Mullan examined feasible routes for both military and railroad passage eastward through the Bitterroot Mountains. In the lower Snake River country, the command frequently traded with local Indian villages for salmon and other supplies and used the numerous Indian trails to traverse canyons and to gain access to the plateau above. The Indians lived in permanent villages, but the army officials noted that their lodges were covered with buffalo skins and mats, indications of trade and travel east of the mountains. On the slopes above the Palouse River, the Indians harvested service berries, wild currants, and gooseberries in great abundance; the "luxuriant bunch grass" that grew everywhere provided excellent feed for the surveyors' horses. Above the scattered groves of trees along the river bottom was "a slightly undulating prairie, destitute of timber." Standing atop Steptoe Butte close to the present border with Idaho in the summer of 1860, expedition topographer Theodore Kolecki described the vast area around the mountain as "rolling prairie, very much resembling a stormy sea" with pine timber commencing four or five miles to the east and stretching to the Bitterroot Mountains.⁴⁰

Lieutenant Henry L. Abbott's survey in the autumn of 1854 of a prospective railroad route from the Sacramento Valley to the Columbia River furnished detailed descriptions of fire-nurtured landscapes, first-hand observations of Indian burning practices, and frequent reference to sizable Indian horse herds. Through the entire route of their travel on the eastern flank of the Cascades from Klamath Lake northward, the Abbott survey found "excellent bunch grass, whortleberries, elder berries and service berries," biotic specimens that thrive in the aftermath of fire. A decade later, officials of the Oregon Central Military Wagon Road surveyed a route from Eugene southeast through the Cascade Range to the headwaters of the Deschutes River. Although the party struggled through the dense forests on the western slope, east of the summit the country was flat, with the higher elevations "covered with black pine, clover grass in abundance, and great quantities of meadow grounds." The surveyors observed places where the forest had been "killed by fire" but found little evidence of undergrowth, either in the black pine or in the yellow pine timber to the southeast. When the group came upon The Dalles-Fort Klamath trail, the surveyors saw signs where a large band of horses had camped the previous night "and from the character of the horse tracks and mockasin (sic) tracks accompanying think it is Indians."⁴¹

³⁹Archibald Campbell to William H. Seward, Secretary of State, February 3, 1869, Records Relating to the First Northwest Boundary Survey Commission, 1853-69, The National Archives, Washington, DC, Microcopy T-606, Roll 1, Image 0539.

⁴⁰Captain John Mullan, Report on the Construction of a Military Road from Fort Walla Walla to Fort Benton (Washington: General Printing Office, 1863), 103-04.

⁴¹Reports of Explorations and Surveys, to Ascertain the Most Practicable and Economical Route for a Railroad from the Mississippi River to the Pacific Ocean, 1854-55, vol. vi, Report of Lieut. Henry L. Abbott, Explorations for a Railroad Route, from the Sacramento Valley to the Columbia River, 1855 (Washington: Beverly Tucker, Printer, 1857. 33 Cong., 2d Sess., Senate Ex. Doc. 78, reprinted in Bert and Margie Webber, Railroading in Southern Oregon and the Founding of Medford (Fairfield, WA: Ye Galleon Press, 1985), 194-200; and diary of B. J. Pengra, entries for July 1865, in Stephen Dow Beckham, The Oregon Central Military Wagon Road: A History and Reconnaissance, USDA, Forest Service, Pacific Northwest Region, Willamette National Forest, Heritage Research Associates, Report 6, Vol. 1 (1981), 28-34.

The descriptions of landscape in the official reports for the eastern slope of the Washington Cascades read much the same: dense underbrush and thickly spaced trees in the higher elevations, gradually giving way to open spaces and a clean understory in the ponderosa-dominated stands at lower elevations. The botanical section of the 1855 railroad surveys through the northern Cascades (known as the “Stevens Report”)⁴² portrays a forested landscape similar to descriptions south of the Columbia River. The representation of the ponderosa-dominated areas is especially striking:

There is [so] little underbrush in these forests that a wagon may be drawn through them without difficulty, forming a striking contrast to the dense thickets of the western slopes. . . . the level terraces, covered everywhere with good grass and shaded by fine symmetrical trees of great size, through whose open foliage the sun's rays penetrate with agreeable mildness, give to these forests the appearance of an immense ornamental park.

The ponderosa zone, according to the Stevens report, extended eastward from Mount Adams about 12 miles and varied in elevation between 2500 and 5000 feet. At higher elevations in the month of August, the survey party encountered “a profusion of berries of several kinds, which the Indians were engaged in collecting.” The report also mentioned large forest fires at lower elevations.⁴³

But what is most striking about the mid-century railroad survey narratives are their similarity to the turn-of-the-century forest reserve reports and the United States Geological Survey (USGS) investigations. With the exception of newly introduced grazing ungulates to the forests—sheep and cattle—and the continued influence of natural and human-caused fire, the forested landscape looked much the same. In brief, market influences in the forest environment of the interior Northwest were still very limited. On the lower slopes of the central Oregon Cascades, a USGS investigation headed by H. D. Langille observed forests “of pure growth . . . [which] are generally open, without much litter or undergrowth, and for those reasons are almost immune from fire.” In the yellow pine country, the report continued, “the forest floor is often as clean as if it had been cleared, and one may ride or even drive without hindrance. As the hills are approached the brush increases.” The investigators estimated that in the “yellow-pine region bordering the timberless area of eastern Oregon” 10 percent of the timbered area had burned recently, 90 percent of the forest “at some remote period.”⁴⁴

John B. Leiberg’s survey of the southern Cascades at the turn of the century acknowledged both the influence of native burning practices and the effects of fire during the early period of white settlement. The composition of the forest in the area surveyed indicated “without any doubt the prevalence of wide-spread fires throughout the region long before the coming of the white man.” But the fires during the Indian period of occupancy “were not of such frequent occurrence nor of such magnitude as they have been since the advent of the white man.” Fires associated with the early settler period, however, were “more numerous and devastated much larger areas.” When settlers learned that burning the forest attracted game, Leiberg surmised, they set the woods on fire. The role of fire in the stands of yellow pine

⁴²The survey through the northern Cascades is usually referred to as the Stevens Report because the Washington territorial governor and Indian agent, Isaac Stevens, was in charge of the survey.

⁴³J. G. Cooper and G. Suckley, *The Natural History of Washington* (New York: Bailliere Brothers, 1859), 9-11. This privately published volume includes segments of the larger report.

⁴⁴H. D. Langille, Fred G. Plummer, Arthur Dodwell, Theodore F. Rixon, and John B. Leiberg, *Forest Conditions in the Cascade Range Forest Reserve, Oregon*, United States Geological Survey, Department of the Interior, Professional Paper 9, Series H., Forestry, 6 (Washington: Government Printing Office, 1903), 78 and 87.

on the eastern slope was clear because of the “noticeable and striking” absence of young growth and underbrush. “The yellow pine,” Leiberg concluded, “is by all odds the best fire-resisting tree in the sylvia of the North Pacific slope.”⁴⁵

Finally, in a Division of Forestry inquiry into the influence of sheep grazing in the Cascade Mountains, Frederick V. Coville affords yet another turn-of-the-century examination of what must be recognized as a humanized landscape. Indian people were “the first manipulators of forest fires in this region,” according to Coville, both in the Willamette Valley, where they annually burned the savannah grasslands and in the Cascades where Indian burning practices created what he termed, “fire glades.” He thought it was an incontestable fact that “at certain seasons it was their custom to set fires in the mountains **intentionally and systematically** (author’s emphasis).” In traveling the length of the Cascades, Coville concluded, “evidences of fire, recent or remote,” had touched every township of forest land. He also reported two relatively new sources of fires—from road building and industrial activity. In the latter instance, he recounted the story of one fire that had burned 15,000 to 18,000 acres in the vicinity of the headwaters of Wood River in the Fort Klamath region. The conflagration began when a camp of men splitting shakes set several small fires to keep mosquitoes away.⁴⁶

Coville’s example of the Wood River fire was only one instance of widespread settler-caused fires during the 19th century. “Fires during the early days of settlement,” one USGS survey reported, were “more numerous and devastated much larger areas. . . . [but] As time has passed, the frequency of forest fires in the region has diminished.” With the increasing commodity value attached to standing timber in the early 20th century, the effort to reduce and eliminate fire gained momentum, eventually assuming the form of the Smokey Bear grand crusade to prevent fire.⁴⁷

With the arrival of ever-increasing numbers of Euro-Americans after 1800, the several millennia of relative⁴⁸ cultural and ecological stability in the Pacific Northwest began to erode. Possessed with unique cultural, social, and economic attributes, the newcomers initiated dramatic cultural and biological modifications that continue to the present day. The aging ex-president John Quincy Adams, speaking on the floor of the House of Representatives in 1846 in favor of settling the Oregon boundary question, may have expressed that newly emerging set of convictions best: “We claim that country—for what? To make the wilderness blossom as a rose, to establish laws, to increase, to multiply, and subdue the earth, which we are commanded to do by the first behest of God Almighty.”⁴⁹

The intruders, slowly at first and then with gathering momentum, imposed on the indigenous people and the regional landscape a markedly different cultural vision, one that led to the gradual—and sometimes spectacular—modification of ecosystems both east and west of the Cascade Range. In the words of one scientist, the last 150 years have witnessed “an unprecedented acceleration” in the ever-changing ecosystems of the region. According to Richard White, as the factor most responsible for precipitating those changes, “white settlement destroyed the Indian Northwest.”⁵⁰

⁴⁵Twenty-First Annual Report of the United States Geological Survey to the Secretary of the Interior, 1899-1900, Part V, Forest Reserves, John B. Leiberg, “Cascade Range and Ashland Forest Reserves and Adjacent Regions,” 277-78 and 288.

⁴⁶Frederick V. Coville, Forest Growth and Sheep Grazing in the Cascade Mountains of Oregon, USDA, Division of Forestry, Bulletin 15 (1898), 19-20, 29-30, and 33.

⁴⁷Leiberg, “Cascade Range and Ashland Forest Reserves and Adjacent Regions,” 227; Eddleman, “Oregon’s High Desert—Legacy for Today,” 2; and Pyne, Fire in America, 161-67.

⁴⁸Here I refer again to Eugene Hunn’s argument that no profound changes had occurred in plateau Indian life for at least 10,000 years. See Hunn, Nch’i-Wana “The Big River”, 19.

⁴⁹Congressional Globe, 29 Cong., 1st sess. (February 9, 1846), 342.

⁵⁰Buechner, “Some Biotic Changes in the State of Washington,” 154.

The worldwide expansion of market capitalism was the great driving force in transforming the human and natural world of the Pacific Northwest. First came the fur men in their quest for beaver pelts, deliberately creating “fur deserts” in one instance to drive competitors away from the region. The decimation of the beaver population occurred early in the Euro-American presence in the Northwest, with consequences to riparian ecosystems that scientists are only beginning to understand today. The fur traders also unknowingly trafficked in other items that brought ecological change, primarily the introduction of exotic plants to the interior country and human contagions that devastated native populations. To anthropologist Eugene Hunn, “the history of Indian-white relations in the Columbia Plateau has been first and foremost a history of the ravages of disease . . . which drastically reduced aboriginal populations.”⁵¹ And, he might have added, opened the way for the re peopling of the region.

In both instances—the intentional and accidental introduction of exotic plant and animal species—agriculturalists were in the vanguard of ecological change in North America.⁵² Farmers, whether their activities were subsistence or commercial, created their own artificial, human-imposed ecosystems on the lands they touched. Westering Euro-Americans brought with them cultural habits and practices and familiar plants and animals; the combined effects of that mix began the slow and then the accelerated transformation of their newly adopted environments. For the interior of the Pacific Northwest, where much of that transformation has taken place in the last century, the end result has been a decisively altered landscape.

It all began, of course, in very innocent and benign fashion. The short-lived Astorian fur trade venture at Spokane House planted what was purportedly a “thriving” garden in 1814; when the Northwest Company shortly took over the post, it raised wheat and potatoes and kept chickens and pigs. But the greatest expansion of agricultural activity during the fur-trade period was the Hudson’s Bay Company’s effort to become self-sufficient; that is, George Simpson’s directive that the company supply its own meat and dairy products and grow its own vegetable and grain crops. After the British government forced a merger with the Northwest Company in 1821, the Bay Company established Fort Colville above Kettle Falls on the Columbia River, an operation that cultivated 370 acres and raised thousands of bushels of wheat by the time the United States and England negotiated the boundary treaty in 1846. Other company posts—Fort Nez Percés or Walla Walla and Fort Okanogan—produced little in the way of food stuffs for export, although the former was a busy center for purchasing horses from the Indians.⁵³

Where climate and soil permitted, the evidence shows clearly that native people readily adopted the agricultural practices of the newcomers. Indian villagers on Puget Sound were growing potatoes in several locations by the 1830s, and Samuel Parker reported in 1836 that the Spokane Indians were cultivating a small field with potatoes, peas, beans, and other vegetables.⁵⁴ Protestant and Catholic groups who began establishing missionary posts in the region during the 1830s expanded the tillable acreage in the next two decades. Although those early agricultural practices did little to disturb existing ecosystems, they were the opening wedge to great ecological change. Moreover, by the 1840s the Pacific Northwest was on the eve of tremendous change with the movement of white emigrants along the Oregon Trail but a portent of things to come. The great catalyst for the transformation of the interior Northwest was the California gold rush.

⁵¹To keep American fur traders away from the company’s valuable Columbia River country, Hudson’s Bay Company officer George Simpson ordered Peter Skene Ogden to create a “fur desert” in the huge drainage of the Snake River. See Schwantes, *The Pacific Northwest*, 60-62. As many as 50,000 native people may have occupied the 260,000 square miles of the Columbia River country. For these estimates and Indian population losses, see Hunn, *Nch’i-Wana “The Big River”*, 31-32.

⁵²For an elaboration of this idea, see White, *Land Use, Environment, and Social Change*, 35-53.

⁵³James R. Gibson, *Farming and the Frontier: The Agricultural Opening of the Oregon Country, 1786-1846* (Seattle: University of Washington Press, 1985), 15-18, and 45.

⁵⁴White, *Land Use, Environment, and Social Change*, 32-33; Parker, *Journal of an Exploring Tour Beyond the Rocky Mountains*, 288.

The hundreds of thousands of people who flocked to California triggered an immediate demand for food-stuffs, lumber, and other materials. That instant market stimulated commercial agriculture and lumbering activity in the Willamette Valley and Puget Sound and led to subsequent gold rushes to southern Oregon in the early 1850s and eventually to the interior Northwest in the late 1850s and early 1860s. As part of its effort to “extinguish” Indian land title, United States officials negotiated a series of forced treaties that ceded huge areas of land in the interior Northwest to the Federal government. Just before the inrush of miners to eastern Oregon and the Snake River country, Federal troops conducted an intensive military campaign to subdue those same people and subsequently confine them to reservations.⁵⁵ The census of 1860 shows only two white “colonization clusters” east of the Cascade Range—one centering around The Dalles with a population of 1340 and another on the Walla Walla River of 1393 but the mining boom that followed quickly made those figures obsolete.⁵⁶

On the eve of the boundary treaty with England, the *Oregon City Spectator* had prophesied that henceforward “the rich smiles of prosperity” would visit the area and “the resources of the country will be developed, and its high worth appreciated.” Appeals of that kind excited the imaginations of acquisitive and adventurous outsiders and Oregon’s growing Euro-American population, which stood at 13,294 in 1850, burgeoned to 52,456 in 1860, 90,923 in 1870, nearly doubled to 174,768 in 1880, and then reached 313,767 in 1890. As table 1 indicates, the same population cohort for Washington grew more slowly until the decade of the 1880s: 1201 in 1850, 11,594 in 1860, 75,116 in 1880, and then exploding to 357,232 in 1890.⁵⁷

Table 1—Oregon and Washington population, 1850-1990

Year	Oregon	Washington	Total
1850	12,093	1,201	13,294
1860	52,465	11,594	64,059
1870	90,923	23,955	114,878
1880	174,768	75,116	249,884
1890	317,704	357,232	674,936
1900	413,536	518,103	931,639
1910	672,765	1,141,990	1,814,755
1920	783,389	1,356,621	2,140,010
1930	953,786	1,563,396	2,517,182
1940	1,089,684	2,736,191	3,825,875
1950	1,521,341	2,378,963	3,900,304
1960	1,768,687	2,853,214	4,621,901
1970	2,091,385	3,409,169	5,500,554
1980	2,633,156	4,132,353	6,765,509
1990	2,842,321	4,867,000	7,709,321

⁵⁵For a discussion of this issue, see William G. Robbins, “The Indian Question in Western Oregon: The Making of a Colonial People,” in *Experiences in a Promised Land: Essays in Pacific Northwest History*, G. Thomas Edwards and Carlos A. Schwantes, eds. (Seattle: University of Washington Press, 1986), 51-67.

⁵⁶Schwantes, *The Pacific Northwest*, 92 and 166; and Meinig, *The Great Columbia Plain*, 201-04.

⁵⁷*Oregon City Spectator*, November 12, 1846; William G. Robbins, “Diminishing Abundance and the Economic Culture of the Pacific Northwest,” in *Sweet Reason: Oregon Essays, Issue 1* Carolyn M. Buan, ed. (Portland: Oregon Committee for the Humanities, 1982), 52; and James W. Scott and Roland L. De Lorme, *Historical Atlas of Washington* (Norman: University of Oklahoma Press, 1988), 35. Until late in the 19th century census figures obviously did not reflect the Indian population.

For the interior region, gold findings were the immediate catalyst for the inrush of people in the early 1860s. The ubiquitous “dust” seemed to be everywhere—on several tributaries of the Snake River, along the streamsides in Oregon’s Blue Mountain country, and farther east in emerging mining districts like Montana’s Last Chance Gulch. The sudden increase in the flow of human traffic up the Columbia River spurred the organization of the Oregon Steam Navigation Company (which soon gained a monopoly on river transportation); boomed the city of Portland as a major entrepôt for the interior country; expanded the economic possibilities for The Dalles and Walla Walla, satellite towns to Portland; and led to the establishment of several fledgling communities—Lewiston, Boise City, and Baker City—as “jumping-off” places for the mines.⁵⁸

That rush of activity in the 1860s to extract minerals from the streams and mountainous slopes of the interior Columbia system was the great opening wedge in the culturally induced transformation of intermontane ecosystems. Mining, especially the 19th century variety, was ecologically disruptive: entire hillsides sluiced away; watercourses silted; and riparian habitats destroyed. The demand for timber for a variety of construction purposes—including trusses for mine tunnels and wooden viaducts to carry water—brought the first large-scale cutting of inland forests. Within a year after gold was discovered in the John Day Valley (June 1862), a sawmill was supplying lumber to miners for flumes and sluices.⁵⁹

Theodor Kirchoff, who passed through the mining country around Mormon Creek in 1868, offered a glimpse of the new ecological reckoning that was dawning in the eastern country: “elevated troughs, long sluices, uprooted ground, raw piles of sand and tailings, heaps of cleanly washed stone, and water for mining rushes in ditches and wooden conduits among boulders and trees.” In Rye Valley, Kirchoff saw evidence of shafts and tunnels with piles of tailings on the slopes and “miles of ditches, carrying water to wash gold.” What is interesting about those observations is the rapidity with which the larger, more heavily capitalized operators with more intrusive forms of technology—hydraulic pipe, reservoirs, and long canals—had replaced the shallow placer miners who relied primarily on the pan and sluice. And it should be noted, this transformation in the regional landscape was well underway before the coming of railroads and steam-powered dredges. The most notable of those early ditching efforts was the construction of a nearly 100-mile waterway from Burnt River to placer deposits near the Malheur River in 1870. During the most productive years of mining activity in the 1860s, the region sprouted a series of short-lived boom towns; among the many were Sparta, Cornucopia, Auburn, and Susanville.⁶⁰

The great transportation arterial to the interior mining regions was, of course, the Columbia River. At the onset of the gold rush, boats moving upriver from Portland reported 15,000 passengers in 1861, 24,500 in 1862, and 22,000 the following year. Although gold-rush populations were notoriously fluid, the historian Dorothy Johansen estimates that, at the peak of the rush, the population of eastern Washington was 75,000. And for the first time since the heyday of the fur trade, traffic began to move downriver as well, this time in the form of the metal-turned-commodity extracted from the streambeds and hillsides of the interior. The Oregon Steam Navigation Company estimated that its monthly shipments of gold to Portland averaged \$400,000 during the 1860s. Other market items were beginning to travel the same route

⁵⁸For general sources on the development of mining in the interior Northwest, see Schwantes, *The Pacific Northwest*, 106, and 172-74; Meinig, *The Great Columbia Plain*, 208-14; Oscar O. Winther, *The Great Northwest: A History* (1947; New York: Alfred A. Knopf, 1968), 220-226; and Dorothy Johansen, *Empire of the Columbia* (1957; New York: Harper and Row, 1967), 265-268.

⁵⁹Jerry Mosgrove, *The Malheur National Forest: An Ethnographic History*, USDA, Forest Service, Pacific Northwest Region (1980), 35-41.

⁶⁰Theodor Kirchoff, *Oregon East, Oregon West, 1863-1872*, ed., trans., and Introduction by Frederic Trautmann (Portland: Oregon Historical Society, 1987), 85-86; Mosgrove, *The Malheur National Forest*, 173; and *An Illustrated History of Baker, Grant, Malheur, and Harney Counties* (n.p., Western Historical Publishing Company, 1902), 137-166.

as well; in 1867, Walla Walla merchants experimented in shipping both flour and wheat to Portland. Aided by newly constructed portage railroads at the rapids and the great falls of the Columbia, those first shipments foreshadowed what would soon become a literal torrent of downriver grain.⁶¹

The external forces driving the ecological transformation of the interior Northwest, hence, were twofold: the thousands of newly arrived immigrants who stayed on to make their homes in the small towns and surrounding countryside, and the external market demand for the commodities that attracted them to the region in the first place. The sharp increase in the flow of traffic through the region boosted the population of The Dalles from 252 people in 1856 to more than 2500 in 1864, with a much larger transient group staying for brief periods. Walla Walla, a small village on Mill Creek, was the transfer point for the movement of people and supplies to the Snake River mining country. The dusty settlement soon had the largest population in Washington, and for a time the community rivaled Olympia in its claims to serve as the territorial capital. Astride the best overland route to the interior, Walla Walla enjoyed the advantages of early settlement and provided, in Donald Meinig's words, "an ever expanding scale and variety of businesses and services."⁶²

While miners, incipient wheat farmers, and town builders were reordering their immediate landscapes, the activities of stockmen were beginning the dramatic alteration of the grassland ecology in the interior Northwest. In a movement that paralleled the mining push east of the Cascades, entrepreneurs began moving large numbers of cattle and sheep onto the prairies and grasslands of eastern Oregon and eastern Washington. Soaring beef prices in the mining districts brought cattlemen and their herds to the creeks and grassy lowlands in the vicinity of The Dalles and several more eastern valleys linked to the Columbia: John Day, Umatilla, Walla Walla, and Yakima. Trailing not far behind were the sheep men, who came with flocks that eventually numbered in the thousands.⁶³ Cattle and sheep grazed throughout the intermontane Northwest by the 1870s, with perhaps Oregon's southeastern quadrant supporting the largest and most spectacular cattle herds.

In their excellent study of the influence of domestic livestock on arid environments, James A. Young and B. Abbott Sparks provide expert witness to the consequences for original plant communities:

The vegetation of the pristine sagebrush/grasslands was rather simple and extraordinarily susceptible to disturbance. The potential of the environment to support plant and animal life was limited by lack of moisture and often by accumulations of salts in the soil. The native vegetation lacked the resilience, depth, and plasticity to cope with concentrations of large herbivores. The plant communities did not bend or adapt; they shattered.

The large number of cattle and sheep consumed grasses that provided a major fuel source for the annual fires that swept the arid interior. The result was the eventual proliferation of big sagebrush and juniper, the virtual elimination of the perennial bunch grasses, and their replacement by exogenous annual grasses.⁶⁴ It would be accurate to say that before railroads penetrated the interior Northwest in the 1880s, extensive alterations to the regional ecology had already taken place on the grasslands.

⁶¹Johansen, *Empire of the Columbia*, 267 and 279; and W. D. Lyman, *An Illustrated History of Walla Walla County, Washington* (Walla Walla: W. H. Lever, 1901), 101.

⁶²Lyman, *An Illustrated History of Walla Walla County*, 57; Schwantes, *The Pacific Northwest*, 106; and Meinig, *The Great Columbia Plain*, 215-217.

⁶³Meinig, *The Great Columbia Plain*, 220-222.

⁶⁴James A. Young and B. Abbott Sparks, *Cattle in the Cold Desert* (Logan: Utah State University Press, 1985), xxi, 27-28; and Stephen Whitney, *A Sierra Club Naturalist's Guide: The Pacific Northwest* (San Francisco: Sierra Club Books, 1989), 254-255.

But the problem of determining cause and effect between human-induced activity and its consequences is not always a simple exercise in observation. As a seasonal employee of the Bureau of Forestry in 1902, William T. Cox participated in a study “to ascertain the source and cause of the annual deposits of sand left by the Columbia, which blows out, forming dunes which bury railroads, orchards, vineyards, and fields of alfalfa.” The youthful disciple of Gifford Pinchot took his job seriously, traversing the Palouse, Walla Walla, Yakima, Wenatchee, Chelan, Methow, Okanogan, Umatilla, John Day, and Deschutes valleys to account for the drifting and blowing sand. “It was pretty evident,” Cox later reported, “that the real cause of the trouble with sand along the Columbia came from crowding of the ranges and breaking up of the sod by sheep and horses.” During the early years of settlement, the Columbia River carried “practically no sand;” nor could the problem be attributable to cattle. The culprits, according to Cox, were horses and sheep that caused the Columbia and Snake rivers to develop huge deposits of sand which commenced “to blow inland after the annual subsidence of the streams.”⁶⁵

Even a casual perusal of the early observer accounts of the mid-Columbia country would have suggested alternative explanations to that cause-and-effect relation. Traveling southeastward from the Walla Walla River on his return trip to the United States in July 1812, Robert Stuart witnessed high winds and blowing sand “sufficiently to produce an almost suffocating effect.” David Douglas, after a nighttime of rain in the same vicinity in June 1826, found “great relief, the atmosphere being cool and the sand prevented from blowing.” The level plain around him, he remarked, was “destitute of timber and comprised of “gravel and sand.” Nathaniel Wyeth, enroute down the Columbia to make his fortune in the fur trade in 1832, left the Hudson’s Bay Company post at Fort Walla Walla and soon encountered “a furious wind” where “the sand flew so as to obscure the air.”⁶⁶

The accounts of wind and blowing and drifting sand mounted with each successive visitor to the mid-Columbia River region. John Kirk Townsend, who reached the junction of the Walla Walla and the Columbia River during the low-water month of September, saw high and rocky banks “interrupted by broad, level sandy beaches.” Thomas Farnham outdid all others in his rhetorical sketches of a desert-like country of “vast rolling swells of sand and clay” as worthless as the “wastes of Arabia.” But the more widely read Fremont described the mid-Columbia/Walla Walla terrain best: “a plain of bare sands, from which the air was literally filled with clouds of dust and sand, . . . this place being one of the several points on the river which are distinguished for prevailing high winds.”⁶⁷

Fremont’s account also provides an alternative explanation for the deposits of sand visible during the period William Cox called “the annual subsidence of the streams.” Moving down the Columbia River from Fort Walla Walla on October 31, 1843, the lieutenant and his entourage toiled through “loose deep sand. . . the stream being interspersed with many sand bars (it being the season of low water).”⁶⁸ Cox was probably correct in claiming that some rangelands were being overgrazed; however, his assumption that overgrazing contributed to the problem of sand in the river and elsewhere would appear to be wide of the mark. Solid evidence suggests that the “drifting and blowing sand” may have been around since the mid-Holocene, or at least since the climate of the interior Northwest began to warm.

⁶⁵Statement Regarding W. T. Cox’s Experiences and Observations in Forestry, 974, File “Cox, W. T.,” Gifford Pinchot Papers, Collections of the Manuscript Division, Library of Congress. For a brief account of William T. Cox’s career as state forester in Minnesota, see William G. Robbins, *American Forestry: A History of National, State, and Private Cooperation* (Lincoln: University of Nebraska Press, 1985), 67-72.

⁶⁶Rollins, ed., *The Discovery of the Oregon Trail*, 75; Davies, ed., *Douglas of the Forests*, 70; and F. G. Young, ed., *The Correspondence and Journals of Captain Nathaniel J. Wyeth, 1831-6* (Eugene: University Press, 1899), 173.

⁶⁷Townsend, *Narrative Journey Across the Rocky Mountains*, 172; Farnham, *Travels in the Great Western Prairies*, 79; and Jackson and Spence, eds., *The Expeditions of John Charles Fremont*, vol. 1, 553.

⁶⁸Statement regarding W. T. Cox’s Experiences and Observations in Forestry, 5; and Jackson and Spence, eds., *The Expeditions of John Charles Fremont*, vol. 1, p. 555.

The industrial revolution came to the interior Pacific Northwest with the rail networks that linked the region to national and international markets in the decade of the 1880s. First in England and western Europe and then in the United States, industrial capitalism marked the onset of increasingly intrusive patterns of human activity in the natural world. In terms of heavily capitalized and broadly based transportation and extractive enterprises, the railroad represented a vastly accelerated move to take advantage of the natural bounty of the intermontane region. At the same moment, distant places like Chicago, New York, Minneapolis-St. Paul, and even London, Berlin, and Paris assumed increasing importance to what took place in the interior Northwest. If “history happened fast” in the region, then steel rails were the transcendent vehicle for that quickening pace of activity.

The rapid building of railroads through eastern Oregon and eastern Washington during the 1880s introduced economic, social, and environmental changes that were revolutionary in their consequences. Increases in population, the formation of new counties, the spectacular expansion in the acreage of cultivated land, and the advent of large-scale industrial mining enterprises were all part of the story. Rail construction through the Walla Walla Valley and around the fringes of the Columbia plain led to an increase in wheat production to more than 2,500,000 acres within a decade. It is important to emphasize that this expansion in tillable acreage marked the emergence of commercial agriculture in a large way, with successful farmers adopting the most improved machinery of the age. Through those commercial developments, wheat—the classic frontier cash crop—replaced the native bluebunch wheatgrass and Idaho fescue on the arid grasslands of the Palouse Hills. One Washington State University scientist concludes that most of the arable land in the Palouse was under cultivation by 1910.⁶⁹ Wheat was an exotic; as such, its cultivation eliminated native plants, flora, and grasses. In short, the market was reshaping the ecology of the Palouse Hills.

The industrial transformation of forest ecosystems in the interior Northwest came more slowly. Distance, the absence of a viable means of transportation, and still sizable timber stands closer to markets in the Great Lakes states limited regional harvests; hence, most logging and milling of lumber before 1900 was directed to local demand. On the fringes of the Columbia plain, mills at Spokane Falls, Coeur d’Alene, Colville, Colfax, Walla Walla, and Yakima cut timber for booming local construction activity. The relation between the up-river forests and the downstream settlements on the Palouse River provides an interesting case study of the reciprocal ties between different landscapes. The forests were sources of firewood and fencing material as well as lumber for building purposes. The first crude mill began operating on the river in 1871, sawing only for nearby construction needs. Those early mills, without access to distant markets, prospered and suffered with the expansion and contraction of the local economy. Lumber capitalists from the Great Lakes States, who began arriving shortly after the turn of the century, subsequently absorbed most of the early enterprises. By that time, the local mills had exhausted the timber that could be easily felled and floated downriver.⁷⁰

The cutting and milling of timber in eastern Oregon follows a similar pattern. Several small sawmills were established in the booming mining districts in the John Day, Burnt River, and Powder River valleys in the 1860s to cut lumber for building materials and timbers for bridge, sluice, and mine construction. The modest productive capacity of those early mills was sufficient to meet the demands of the boom-and-bust mining economy between 1860 and 1880. Although much of the easily accessible timber adjacent to the fledgling mining communities had been cut, the vast interior of the Blue Mountain forests was still untouched. The manipulations and maneuvers of distant capitalists, however, soon altered that relatively slow pace of activity.

⁶⁹Oliphant, “History of the Livestock Industry in the Pacific Northwest,” 4-5; Johansen, *Empire of the Columbia*, 317-318; Whitney, *A Sierra Club Naturalist’s Guide*, 255; and Helmut K. Buechner, “Some Biotic Changes in the State of Washington, Particularly During the Century, 1853-1953” *Research Studies, State College of Washington* 21 (1953), 168-169.

⁷⁰John Fahey, *The Inland Empire: Unfolding Years, 1879-1922* (Seattle: University of Washington Press, 1986), 188-189; Robert Wayne Swanson, “A History of Logging and Lumbering on the Palouse River, 1870-1905” (M. A. Thesis, Washington State University, 1958), 2, 13, 17, 45; and Keith C. Peterson, *Company Town: Potlatch, Idaho, and the Potlatch Lumber Company* (Pullman: Washington State University Press, 1987), 6-12.

The completion of a transcontinental railroad in 1884, linking the Columbia River—via the Blue Mountains and Grand Ronde Valley—to the Union Pacific Railroad at Huntington on the Snake River, accelerated the pace of industrial activity in the forests of eastern Oregon.⁷¹ Using a variety of tactics, including dummy entrymen, David Eccles, a western lumberman, began purchasing blocks of timber in the early 1880s to supply railroad ties for the construction of the Union Pacific subsidiary, the Oregon Short Line. With a group of associates, Eccles incorporated the Oregon Lumber Company in 1889, soon to emerge as the leading producer of western pine lumber in the State.⁷²

To tap the timber wealth of the southern Blue Mountains, Eccles and his partners formed a subsidiary corporation, the Sumpter Valley Railroad Company, and constructed a narrow-gauge line 19 miles up the Powder River. The first logs rolled down the route to Baker City and the company's state-of-the-art mill on August 1, 1890, thus establishing a regimen for harvesting, transporting, and milling timber that lasted through the Second World War. In the succeeding years, the railroad pushed deeper into the mountains, and by 1910, the line extended 80 miles to Prairie City and the John Day Valley. In the late 1890s, mining boomed throughout the Sumpter Valley region, creating business for the Oregon Lumber Company, especially in mine timbers, and bringing a huge volume of traffic for the railroad. Eventually, several operators built small sawmills in Sumpter to cut timbers and lumber for the mines. But the railroad's long-term, bread-and-butter traffic centered on the area's impressive timber stands.⁷³

The population growth for Baker County between 1880 and 1910 reflects the increased human activity along the extensive Sumpter Valley Railroad and its several spur lines. As table 2 indicates, both mining and lumbering operations attracted people to the area, with the county's population growing from 4616 in 1880 to 18,076 in 1910. The expanding population base and an increasingly sophisticated and productive technology suggest the influence of industrial activity in transforming the landscape of the southern Blue Mountain region. The railroad was itself an intrusive force—linking resources, processing facilities, and markets—enabling lumbermen to gain access to stands remote from manufacturing sites. When he conducted a reconnaissance through the region for the Federal government in the early 20th century, H. D. Langille reported that “the destruction of the timber [was] almost complete” along much of the Oregon Lumber Company's railroad.⁷⁴

Table 2—Population of Baker County

Year	Population
1870	2,804
1880	4,616
1890	6,764
1900	15,597
1910	18,076
1920	17,929
1930	16,754

⁷¹Randall V. Mills, “A History of Transportation in the Pacific Northwest,” *Oregon Historical Quarterly* 45 (1946), 291-292; and Enoch A. Bryan, *Orient Meets Occident: The Advent of the Railways to the Pacific Northwest* (Pullman: Students Book Corporation, 1936), 162-163. Henry Villard, the financial guru behind the Oregon Railway and Navigation Company, also engaged in the wholesale advertising and promotion of the settlement of the Powder River Valley and adjacent areas. See James B. Hedges, *Henry Villard and the Railways of the Northwest* (1930; New York: Russell & Russell, 1967), 123-126.

⁷²Mallory Hope Ferrell, *Rails, Sagebrush, and Pine: A Garland of Railroad and Logging Days in Oregon's Sumpter Valley* (San Marino, CA: Golden West Books, 1967), 9-13; Mosgrove, *The Malheur National Forest*, 71; Baker City *Record Courier*, November 7, 1946; and Shirley T. Moore, ed., *Sumpter Valley Railway*, USDA Forest Service, Wallowa-Whitman National Forest, Pacific Northwest Region, n.d., n.p.

⁷³Ferrell, *Rails, Sagebrush, and Pine*, 13-33.

⁷⁴Langille is quoted in Mosgrove, *The Malheur National Forest*, 71.

Although the railroad did nothing more than the bidding of its directors, a company history provides an appropriate commentary on the increased production made possible by the new transportation technology: “As the rails of the Sumpter Valley Railway were pushed up the Powder River Valley, timber was taken from each gulch and creek along the way.” The leading lumber trade journal in the Pacific Northwest, *The Timberman*, noted in 1903 that the Oregon Lumber Company was using “the only steam skidder in the state. ... to daylight (author’s emphasis) the forest around Whitney.”⁷⁵ The changing landscape of the southern Blue Mountains at the turn of the century was clearly a direct consequence of an impressive industrial technology designed exclusively to maximize production and to reward its financial backers.

The emergence of large-scale lumber production in the interior Northwest was directly linked to the four transcontinental railroads—the Northern Pacific (1883), Oregon Short Line (1884), the Great Northern (1893), and the Milwaukee Road (1909). Those ties were first evident in the vast Inland Empire, where the absence of viable, long-distance water transportation made railroads the critical element in marketing lumber beyond the region. Railroads were first put to use supplying timber for constructing branch lines to the mining districts and then for hauling lumber to those new centers of mineral production. David Mason, an early forester-authority on timber and lumber output in the region, pointed out that it was not until the 20th century “that the lumber industry of the Inland Empire began to do more than supply local demands.”⁷⁶

Spokane, the transportation hub of the region’s dramatic burst in population, spurred lumber production in northeastern Washington to significant heights well before the turn of the century. Serving as the center of a vast network of rail lines that serviced the wheat-producing regions to the south and west and mining districts in Idaho and southern British Columbia, Spokane’s population grew exponentially after the Northern Pacific built its line through the community in 1881.⁷⁷ As table 3 indicates, Spokane County’s increase in population from 4262 in 1880 (fewer than Baker County!) to 139,404 in 1910 far outpaced the rate of growth for any county for any decade in all of eastern Oregon and eastern Washington. Because of the proximity of timber to the north and east of Spokane, those growth figures also imply a heavy demand for lumber to supply the construction needs of the burgeoning community.

Table 3—Population Growth for Spokane County

Year	Population
1880	4,262
1890	37,487
1900	57,542
1910	139,404
1920	141,289
1930	150,477

⁷⁵Ferrell, *Rails, Sagebrush, and Pine*, 49. *The Timberman* is quoted in Ferrell, 49. Langille reported that stamp mills and mining were consuming a “considerable amount of timber. See Mosgrove, *The Malheur National Forest*, 72.

⁷⁶David T. Mason, *Timber Ownership and Lumber Production in the Inland Empire* (Portland: Western Pine Manufacturers Association, 1920), 11-13.

⁷⁷For general histories of the development of the Spokane area, see John Fahey, *Inland Empire: D. C. Corbin and Spokane* (Seattle: University of Washington Press, 1965); and Fahey, *Inland Empire*.

Because Spokane dominated retail trade with its extensive hinterland, the city occupied an important position in the lumber business of the Inland Empire. Two large sawmills operated along the Spokane River before 1900; one of them, the Sawmill Phoenix, located in Spokane proper, shipped its logs on the Spokane Falls and Northern Railroad from timberlands near present-day Springdale. But when the major railroads lowered shipping rates in 1894, local lumber brokers began purchasing lumber from Puget Sound producers, practices that continued until the early 20th century, when Great Lakes lumber capitalists began looking to the Pacific Northwest for virgin stands of timber.⁷⁸

Brisk regional construction activity, especially in bustling Spokane, continued to drive the lumber market in northeastern Washington until the First World War. But a slowdown in mining enterprises and rail construction brought an end to the economic boom, and the population of Spokane County grew by fewer than 2000 people between 1910 and 1920. It is ironic that the economic slowdown occurred simultaneously with the end of the massive transfer of timberland from public to private ownership, much of it to buyers from the Great Lakes States. David Mason points out, by 1909 forests that had not been transferred to the private sector were in National Forests.⁷⁹

Historians and the public alike have celebrated the huge land purchases of Frederick Weyerhaeuser and his cohorts at the turn of the century. Although he is not as well known, F. A. Blackwell, who worked in Minnesota lumber camps as a youth, may represent the more typical early 20th century lumberman. Blackwell began purchasing timberlands in northern Idaho and northeastern Washington until he had amassed holdings in excess of 100,000 acres. And he was innovative at the production end, building a large flume that hurtled logs into a stream leading to Spirit Lake. In time, Blackwell was running sizable mills at Spirit Lake and Ione, operations linked to the Northern Pacific main line near Coeur d'Alene by 106 miles of steam railroad. But Blackwell's purchases and expansion in production facilities came in the midst of Spokane's greatest period of growth. When the regional economy slowed just before the Great War, Blackwell turned up victim to the economic shakeout and lost control of everything—timberlands, railroads, production facilities, and townsites.⁸⁰

Blackwell's story was symptomatic of larger problems in the interior Northwest where economics and ecology intermixed in a symbiotic bond as a consequence of the feverish speculation in timberland purchases in the early 20th century. Inland Empire lumbermen aggressively sought buyers in distant eastern markets in a desperate effort to pay off their indebtedness after the downturn in the local economy. Those measures, however, failed to resolve their problems in the long run, because the lumber market remained glutted—except for a blip or two—for the entire period between 1910 and the outbreak of the Second World War. David Mason captured that veritable “catch-22” situation for Inland Empire producers at the end of the First World War:

*The lumber industry is not in a stable condition. This is made evident by the exceedingly small profits in the business, the existence of much unused milling capacity while additional capacity is being developed, and the constant tendency to cut more lumber than the market will absorb. The principal cause of instability is the great pressure to liquidate the stumpage investment.*⁸¹

⁷⁸Fahey, *Inland Empire*, 189.

⁷⁹Fahey, *The Inland Empire*, 201; and Mason, *Timber Ownership and Lumber Production in the Inland Empire*, 16-17.

⁸⁰Craig E. Holstine, “A History of the Colville National Forest” (M.A. thesis, Washington State University, 1978), 35-37; and Fahey, *The Inland Empire*, 194-197.

⁸¹Fahey, *The Inland Empire*, 201; and Mason, *Timber Ownership and Lumber Production in the Inland Empire*, 13-14. For an extended discussion of the industry's problems with overproduction, see William G. Robbins, *Lumberjacks and Legislators: Political Economy of the U.S. Lumber Industry, 1890-1941* (College Station: Texas A & M University Press, 1982), 5-12.

Less observable in the lumber producers' cash-flow statistics are the consequences for forest lands throughout the Pacific Northwest. For the interior region, the pursuit of the bottom line meant production-driven business practices that focused on taking only the best and most marketable timber from the woods and leaving huge amounts of debris on the ground. Waste, as Richard White has indicated, had little economic meaning in an age when the supply of timber seemed inexhaustible and perpetually glutted markets confronted the operator. The result of those practices is evident in some of the worst forest fires in the region's history, fires fed in part by the accumulation of heavy fuels lying on the ground. In contrast with earlier conflagrations, the fires that burned through logging debris were hot, consuming duff, seedlings, and standing trees alike. In truth, the new fire regimes represented a much more intrusive element in the forest ecosystem.⁸² Those new conditions also underscore the degree to which economics and ecology were entwined in the industrial age.

If the railroad represented the opening wedge of the industrial revolution in the Inland Empire, the coming of steel rails to central and south-central Oregon had an even more dramatic effect in redesigning the regional landscape. Until the railroad reached Klamath Falls in 1909 and Bend in 1911, distant markets had little effect on the great ponderosa forests that stretched along the eastern slope of Oregon's Cascade Range. The effect of those newly built and efficient transportation arterials was to link those magnificent stands of ponderosa pine with outside markets, thus setting in motion the large-scale industrial production of lumber in the region. The Bend *Bulletin* heralded the "opening up" of this last great western pine region and the building of state-of-the-art facilities to mill the lumber as a "dream" become "actuality." The euphoria of the time and the setting emphasized pride in the volume of timber harvested and uninhibited boasting about the production records established in the mills. Less obvious in the historical literature were the changes taking place in the forested outback, beyond the towns and logging camps of central Oregon.⁸³

In the struggle for profits in volatile and often glutted markets, the central Oregon districts possessed certain advantages over their eastern Washington counterparts: two-thirds of the central Oregon timber was privately owned; the area had relatively more even terrain; it was closer to California markets; and it had a greater volume of forest in pure stands of ponderosa pine. In its congressionally mandated forest surveys in the mid-1930s, the Forest Service found "pure or nearly pure" stands of ponderosa "reaching through the whole north-south extent of the State and from the lower slopes of the Cascades on the west to open desert lands on the east." And when the rails reached those virgin stands, other competitors were quick to notice. Ralph H. Bockmier, an eastern Washington producer, observed that the "Oregon competition," especially the mills at Bend and Klamath Falls, created competitive problems in the ponderosa trade immediately after the First World War.⁸⁴

The population figures for the leading timber-producing counties in eastern Oregon and eastern Washington reflect that southward shift in lumber production (see appendices A and B). Oregon's newly created (1915) Deschutes County grew from 9622 in 1920 to 14,749 in 1930, and even during the decade of the Great Depression, a period of slow national growth, the population of the county increased by more than 25 percent. The influence of the railroads on Bend, the center of manufacturing in Deschutes County, is equally striking: 536 people in 1910 and 5414 in 1920. The population increases for Klamath County, where the Weyerhaeuser Company opened a huge mill in 1929, are even more impressive: 8554 in 1910; 11,413 in 1920; and 32,407 in 1930.⁸⁵

⁸²White, *Land Use, Environment, and Social Change*, 88-91; and Pyne, *Fire in America*, 336-342.

⁸³Thomas R. Cox, "Closing the Lumberman's Frontier: The Far Western Pine Country," (manuscript copy in the author's possession), 1; and Philip Cogswell, Jr., "Deschutes Country Pine Logging," in *High and Mighty: Select Sketches about the Deschutes Country*, Thomas Vaughan, ed. (Portland: Oregon Historical Society, 1981), 236-241.

⁸⁴USDA Forest Service, *Forest Statistics for Klamath County, Oregon*, Forest Survey, Pacific Northwest Forest Experiment Station (February 1, 1936), 1; and Ralph H. Bockmier, Sr., "Inland Empire Lumber Industry over a Period of Sixty Years, 1900-1965." Typescript, R. H. Bockmier Lumber Corporation, 1967, in Washington State University Archives, Cage 387, p. 16-18; and Fahey, *The Inland Empire*, 207.

⁸⁵Cogswell, "Deschutes Country Pine Logging," 241.

During those same decades, Washington's leading lumber-producing counties—Chelan, Ferry, Kittitas, and Stevens—all lost population, with some operators and workers shifting to the more active pine country south of the Columbia River.⁸⁶ Other mitigating factors (for example, mining) may explain the declining population in those counties; however, in an age of still labor-intensive activity in the lumber industry, the huge volume of production of the Oregon pine mills tells most of the story. Beginning in 1925 when the first aggregate figures are available, the timber harvests in eastern Oregon far-outstripped those for eastern Washington. Indeed, Klamath County's lumber output in 1925 alone nearly equaled the total production for all of eastern Washington.⁸⁷

Technology, natural competitive advantages over rival producing regions, and the virtual absence of any constraints on private timber harvesting (except for the market), contributed to the halcyon years of lumber production in the pine belt from Bend southward to Klamath Falls. But more than any other factor, the splendid, nearly pure stands of ponderosa pine explain the booming productivity of the area's mills. The USGS survey of the volume of sawtimber on the eastern slopes of the Cascades in 1900 indicated a total of 1,450,420 acres in "yellow pine;" of that huge quantity, only 33,700 acres had been logged. Moreover, the mid-1930s Forest Survey for Klamath County noted that the richest commercial belt of timber grew on terrain ideally suited to railroad and truck-road construction, much of it within a 30-mile radius of Klamath Falls. The survey also underscored the importance of the market in remaking the area's forest ecosystem: ponderosa pine comprised more than 96 percent of the total production between 1925 and 1934.⁸⁸

The opening of the Weyerhaeuser Company's big mill in 1929 helped sustain the Klamath cut, even during the doldrums of the Great Depression. The county's total output remained above 300- and 400-hundred thousand board feet for most of the period, with the exception of 1932 when it dropped to 196,591. Production then rose to more than 600,000 board feet in 1936, remained above that figure through the early years of the Second World War, dropped gradually to a postwar average of about 200,000 board feet through the early 1960s, and then began an upward swing, triggered in part by Weyerhaeuser's decision to abandon select logging.⁸⁹ The move toward clearcutting—to what managers termed more cost-effective, "even-aged" stands—meant the abandonment of the mixed-aged forests that reflected selective harvesting. In its place, the company began to practice intensified forest management on its cutover lands.

Eventually, weak lumber prices and a decline in the supply of old-growth pine curtailed production at Weyerhaeuser's Klamath Falls sawmill, one of the largest in Oregon. The company announced that it would lay off nearly half of its 450 employees in mid-1985, citing the reduced volume of large ponderosa pine as a precipitating factor. The *Portland Oregonian* reported that the harvests of Klamath timber included stands that dated before the American Revolution. The hemorrhage of mill closures that occurred elsewhere in the ponderosa region in the 1980s included the complete shutdown of Weyerhaeuser's large mill in the small town of Bly.⁹⁰ Markets, corporate business strategies, and the management decisions

⁸⁶Bockmier, "Inland Empire Lumber Industry," 26; and Fahey, *The Inland Empire*, 207.

⁸⁷Brian R. Wall, *Log Production in Washington and Oregon: An Historical Perspective*, USDA Forest Service, Resource Bulletin PNW-42 (1972), 15-19, and 30-45.

⁸⁸John B. Leiberg, "Cascade Range and Ashland Forest Reserves and Adjacent Regions," *Twenty-First Annual Report of the United States Geological Survey to the Secretary of the Interior, 1899-1900*, Part V, Forest Reserves, 273; and *Forest Statistics for Klamath County, Oregon*, 3-6.

⁸⁹Wall, *Log Production in Washington and Oregon*, 41; and Cox, "Closing the Lumberman's Frontier," 12.

⁹⁰*Portland Oregonian*, February 21, 1985.

of public land agencies affected the volume and species of logs flowing to the mills. In the long run, however, in the Klamath country as elsewhere, the heavy flow of market-selected species to the mills forged both a depressed local economy and a newly fashioned forest landscape. The industrial age proved again the close integration of the seemingly separate worlds of economics and ecology.

But it is Bend that provides the more fascinating story of the conjuncture between culture and nature, between economics and ecology, between a thriving and bustling lumber town and its timbered wealth. Bend's large-volume pine manufacturers, according to historian Thomas Cox, "represented the last, spectacular flowering of the old order," a production system predicated on liquidating standing timber as quickly as markets and the technical ability to produce permitted. The story of the Brooks-Scanlon and Shevlin-Hixon operations parallels that of other Great Lakes lumber capitalists who began purchasing large tracts of timber in the Pacific Northwest in the early years of the 20th century. Through mergers and buyouts, Shevlin-Hixon had amassed more than 200,000 acres of prime ponderosa timber when its immense mill began sawing lumber on March 3, 1916; Brooks-Scanlon, with a small but rapidly expanding acreage, opened milling facilities with a similar productive capacity the following month. The Bend *Bulletin* was ecstatic about those developments:

The dream, Bend, the sawmill and lumbering center of Central Oregon is now an actuality. . . . After years of "watchful waiting" by men who were possessed with faith that one day saws would be humming and that the vast area of Deschutes timber would be manufactured at Bend, they have today to take a 10-minute walk from the center of town to see that realization of their dreams.⁹¹

Each of the large pine manufacturing facilities employed about 600 men, with a ratio of perhaps two workers engaged in the logging end of the business for every mill operative.⁹² The continually expanding cutting capacity of the plants eventually reached 200 million board feet a year, a prodigious amount, the impressive volume of timber tributary to Bend notwithstanding. For nearly three decades, the town and the surrounding countryside bustled with the kind of activity that prompted the Forest Service to boldly proclaim: "The history of the economic development of Deschutes County is largely the history of its lumber industry."⁹³ A strong case can be made that Bend was the most timber-dependent community in Oregon, or at least until the timber began to run out and entrepreneurs launched an effort to capitalize on a resource of another kind, namely snow.

The relatively even terrain provided a showcase of sorts for experimenting with new, highly productive technological devices in the woods. Railroads spanned out from Bend in three directions to the rich stands of ponderosa pine, where loggers began using the highly efficient steam-powered McGiffert loader to hoist logs onto flatcars. The subsequent development of the Ledgerwood skidder and the gasoline-powered caterpillar tractor further advanced the volume of timber that loggers were able to move in a single day. And then at the close of the Second World War, the companies quickly turned to the most revolutionary

⁹¹Cox, "Closing the Lumberman's Frontier," 3-4; and Cogswell, "Deschutes Country Pine Logging," 238-246. The Bend *Bulletin*, March 3, 1916. The *Bulletin* is cited in Cogswell.

⁹²I made a similar calculation for the ratio of workers employed in sawmill and logging operations on Coos Bay during the days of steam-powered logging. That ratio changed with the introduction of the chain saw and gasoline-driven engines to the woods. See William G. Robbins, *Hard Times in Paradise: Coos Bay Oregon, 1850-1986* (Seattle: University of Washington Press, 1988), 41.

⁹³Cogswell, "Deschutes Country Pine Logging," 246-47; and Philip A. Briegleb, *Forest Statistics for Deschutes County, Oregon*, USDA Forest Service, Pacific Northwest Forest Experiment Station (May 18, 1936), 6.

and productive tool of them all, the gasoline-powered chain saw. With the steady improvement in the performance of automotive vehicles for transporting logs, Shevlin-Hixon and Brooks-Scanlon gradually turned to the use of log trucks to haul timber from ever-greater distances.⁹⁴

The voracious appetite of the big mills in Bend began to place pressure on the available timber supply as early as the 1930s when Brooks-Scanlon officials asked the Forest Service to release a greater volume of timber to sustain the viability of the local economy. The supply problem for the mills rested in the heavy cutting that already had taken place on private lands. The Federal Forest Survey of 1936 for Deschutes County reported 41 percent of ponderosa pine forests in private ownership and 58 percent in the National Forests. With the volume of privately held timber rapidly diminishing, lumber executives were casting about for fresh stands. Especially significant for the future of the forest ecosystem was the fact that ponderosa pine comprised more than 99 percent of the timber harvested.⁹⁵

The Deschutes County Forest Survey indicated that the Bend mills altogether had produced an average annual cut of 235 million board feet between 1925 and 1934, a volume "in excess of the sustained-yield capacity of the forest land of the county." Of the 210,000 acres of cutover land in the county, 68 percent had "practically no trees of saw-timber size." Therefore, privately owned timber could sustain the existing mills in Bend for only 15 to 25 years "depending on what logs might be economically hauled in from Jefferson and Klamath Counties." When private sources were exhausted, the survey concluded, restricted, sustained-yield sales of public timber "will mean a drastic reduction of the average annual lumber production of the county." Subsequent developments would show that the Forest Survey erred only in timing: the private stands were gone within 10 years. The manufacturing output for Deschutes County during the 1940s tells the story:⁹⁶

Table 4—Lumber production for Deschutes County

Year	Thousand board feet	Year	Thousand board feet
1940	258,050	1946	194,605
1941	196,672	1947	14,619
1942	248,334	1948	47,918
1943	200,743	1949	33,289
1944/45	no data	1950	42,499

A few short years after the nose-dive in production, Brooks-Scanlon purchased the Shevlin-Hixon timberlands and milling facilities and promptly closed the latter, putting 850 people out of work. A booming postwar economy and the emergence of a burgeoning tourist and winter-sports industry undoubtedly mitigated the economic fallout from the mill closure. But in a larger sense, the quick liquidation of the privately held ponderosa stands merely repeated old and familiar patterns in the industry, patterns repeated elsewhere in the Pacific Northwest, the Great Lakes States, and in the South.⁹⁷ More difficult and complicated to assess are the effects of those industrial and market-driven forces on the forest landscape.

Although the industrial penetration of the great timber stands in the Blue Mountains began in 1890 with the Oregon Lumber Company and its Sumpter Valley Railroad, that operation remained the only large-scale effort to capitalize on the mixed pine and fir forests until well into the 1920s. Distance from markets, difficult terrain, and the lack of viable transportation arterials explain the restricted commercial entry

⁹⁴Cogswell, "Deschutes Country Pine Logging," 250-251; and Cox, "Closing the Lumberman's Frontier," 9.

⁹⁵Briegleb, *Forest Statistics for Deschutes County*, 3-5.

⁹⁶*ibid.*, 6. The yearly production figures are listed in Wall, *Log Production in Washington and Oregon*, 40.

⁹⁷Cogswell, "Deschutes Country Pine Logging," 257-259; Cox, "Closing the Lumberman's Frontier," 9; and William G. Robbins, "The Social Context of Forestry: The Pacific Northwest in the Twentieth Century," *Western Historical Quarterly* 16 (1985), 413-427.

into the area. But even in the face of depressed lumber prices, the western pine industry continued to expand in the years after the First World War, spurred on in part by lumber capitalists from the Great Lakes States and the South, who were seeking fresh sources of timber.⁹⁸

That reborn effort to gain access to Blue Mountain timber came at a time and in places where the Federal government controlled much of the forest land. Hence, lumber capitalists were forced to negotiate timber purchases through the Forest Service and to abide by the agency's specified cutting regulations. The Kinzua Lumber Company, with sizable holdings of its own on the northwesterly reaches of the Blue Mountains, began cutting into prime stands of ponderosa pine in Wheeler County in 1928. Until the Kinzua firm appeared on the scene, four small mills had cut a small volume of lumber for a very limited local market. But Kinzua's large-scale commercial venture linked the rich timber stands with the industrial world, and in the first eight years of the operation, the firm had cut nearly 28,000 acres. The production accomplishments of the Kinzua mill, like those in Bend and Klamath Falls, depended on access to nearly pure stands of ponderosa pine and a branch line of the Union Pacific Railroad.⁹⁹

There was no mystery behind the successes of the ponderosa mills in the years leading up to the Second World War. Ralph H. Bockmier, a large-volume Spokane lumber dealer, recalled late in life that eastern markets in particular had a great preference for ponderosa and Idaho white pine. Because the stumpage value of mixed stands was low, the market dictated "select cutting." What that meant for the mixed-species' forests of northeastern Washington and northern Idaho was the wholesale cutting of pine, while white fir, Douglas-fir, larch, and Engelmann spruce were left standing. Reports to the Forest Service District 6 office in 1911 indicate a growing demand for "yellow pine" on the Whitman National Forest along the Sumpter Valley Railroad and increased harvesting of the same species in the pine belt tributary to Upper Klamath Lake. The market attractions of ponderosa pine literally made it the "tree of choice" for most lumbermen. Not until the building boom after the Second World War was the interior Northwest able to successfully market species other than pine. What the forest economist Brian Wall calls the "more mixed timber inventory of the Blue Mountains" hints at the selective approach of capitalists to that region as well. The production statistics for eastern Washington clearly show the early preference for ponderosa pine:¹⁰⁰

<u>Year</u>	<u>Species</u>	<u>Percentage of cut</u>
1925	Ponderosa pine	72
	Douglas-fir	14
1970	Ponderosa pine	35
	Douglas-fir	33

With a relatively good market for finished pine in the 1920s, it is not surprising that westerly looking lumber capitalists would continue their hunt for untapped sources of ponderosa. At the moment the Kinzua mill was coming on line, developments at the southern end of the Blue Mountains bordering on the Harney Basin were moving in a similar direction. And there, too, ponderosa pine comprised by far the most important component in the forest complex. But unlike other points of access to Blue Mountain

⁹⁸Thomas R. Cox, "Frontier Enterprise vs. the Modern Age: Fred Herrick and the Closing of the Lumberman's Frontier," forthcoming in the *Pacific Northwest Quarterly*, manuscript copy in the author's possession, 3; and Morton J. Lauridsen, *Forest Statistics for Grant County, Oregon*, from the inventory phase of the Forest Survey, USDA Forest Service, Pacific Northwest Forest Experiment Station (August 5, 1937), 8.

⁹⁹Cox, "Frontier Enterprise vs. the Modern Age," 3-4; and F. L. Moravets, *Forest Statistics for Wheeler County, Oregon*, from the inventory phase of the Forest Survey, USDA Forest Service, Pacific Northwest Forest Experiment Station (June 10, 1937), 5-6.

¹⁰⁰Bockmier, "Inland Empire Lumber Industry," 16; and Wall, *Log Production in Washington and Oregon*, 21; Report of Offices in District 6, 1911, U. S. Forest Service, Portland Regional Office, Regional Forester-National Forests, 1904-1916, box 1, Record Group 95, Seattle Branch, National Archives and Record Center, 24-25; and Wall, *Log Production in Washington and Oregon*, 17.

timber, the forested slopes fronting the arid basin country were largely in public ownership.¹⁰¹ For the prudent lumberman, therefore, the assurance of cutting rights to National Forest timber was a prerequisite to investment.

Fred Herrick, a Michigan-born lumberman who made a fortune and became a buccaneer of sorts in Idaho's white-pine country, initiated the move into the southern Blue Mountains. Juggling railroad construction with the promise of cutting rights to nearly a billion board feet of National Forest timber, Herrick completed a Union Pacific line from Crane to Burns in 1924 and continued building the promised road northward until he reached the end of his financial rope. The Forest Service canceled Herrick's timber contract, disqualified him from future bidding, and eventually awarded a new contract to the Chicago-based Edward Hines Lumber Company. Hines quickly completed the railroad up the Silvies River to Seneca and built almost overnight a modern, electrically operated plant of steel construction that cut its first pine log on January 27, 1930.¹⁰²

The opening of the Hines mill boosted the population of Burns to 2599 by 1930, an increase of 154 percent. Skirting on the verge of bankruptcy during the early years of the Depression, the company eventually profited through its Forest Service contract and through the continued purchase of additional stands of private timber. And where Shevlin-Hixon was able to parlay its holdings into 34 years of operations, the Hines Lumber Company played out its hand as Harney County's only major industrial complex and largest employer for 50 years. During that period the mill provided work for a largely static county population, one that had begun to decline by the 1970s. Finally, with a depressed lumber market and an inefficient and obsolete plant badly in need of renovation, the Hines Lumber Company closed its doors in 1980, devastating Harney County and putting nearly 1000 people out of work.¹⁰³ The old Hines' facilities subsequently reopened, but under new management with a drastically reduced work force.

With the ending of the Second World War and improved markets for lumber other than pine, the gap in manufacturing volume between eastern Oregon and eastern Washington narrowed. Much of the increased production in Washington had to do with accessibility to the mixed fir and pine forests on the eastern slope of the Cascade Range. Yakima, Kittitas, Chelan, Okanogan, and Ferry counties all reported increases in log production at the onset of the 1950s. But unlike the industrial activity in Oregon's booming pine belt before the war, the increased output in eastern Washington took place in the midst of some local economies that were more diversified. Yakima County, which has set the pace for Washington in fruit production for most of the 20th century, also led the State's eastern counties in wood manufacturing during the 1960s.¹⁰⁴

But production records suggest neither economic nor environmental stability. Industrial technology, the factor largely responsible for increases in output during the 20th century, has exerted an extraordinary influence in reshaping landscapes. In the corporate executive's account books, industrial technology also has contributed mightily to reducing labor as a factor in production. For the highly productive timber counties in eastern Washington, the influence of mechanized technology—as elsewhere in the Pacific Northwest—is clearly evident. As table 5 illustrates, an inverse ratio exists between production and population for the period from 1930 to 1970. Indeed, for the more timber-dependent counties—Chelan and Ferry—log production rose dramatically while a net decline in population occurred. And although the population of Okanogan County increased slightly during the same period, its volume of log production nearly doubled.

¹⁰¹F. L. Moravets, Forest Statistics of Harney County, Oregon, from the inventory phase of the Forest Survey, USDA Forest Service, Pacific Northwest Forest Experiment Station (May 7, 1936), 3-5.

¹⁰²Cox, "Frontier Enterprise vs. the Modern Age," 5-8, and 13-19; and Moravets, Forest Statistics for Harney County, Oregon, 6.

¹⁰³Moravets, Forest Statistics for Harney County, 7; and Portland Oregonian, November 30, 1980.

¹⁰⁴Wall, Log Production in Washington and Oregon, 21.

Table 5—Lumber production and population in selected counties, 1930-1970

Year	Chelan		Ferry		Kittitas		Okanogan		Yakima	
	Prod.	Pop.	Prod.	Pop.	Prod.	Pop.	Prod.	Pop.	Prod.	Pop.
1930	29,762	5,325	32,330	4,292	80,619	18,154	63,349	18,519	2,087	77,402
1940	52,326	5,549	31,820	4,701	49,926	20,230	101,462	24,546	54,219	99,019
1950	57,853	4,860	75,583	4,096	69,345	22,235	110,191	29,131	86,930	135,723
1960	74,545	4,569	123,717	3,889	149,564	20,467	103,800	25,520	146,960	145,112
1970	65,491	4,439	144,344	3,655	87,627	25,039	110,517	25,587	230,718	144,971

The tremendous timber harvests in the interior Northwest that began in the 1920s continued for more than four decades. The attractions of distant metropolitan markets propelled and sustained those years of record production. In the process, the forests as well as the fields and mineral areas of the interior Northwest were integrated more closely into national and international market arrangements. Those developments further intensified the symbiosis between two landscapes—the resource-abundant interior Northwest and growing urban centers in California, the Midwest, and elsewhere. Although both environments were dramatically transformed, it was the demand for commodities in the metropolis that largely directed and ordered the pace of change in the hinterland.¹⁰⁵ With access to an increasingly more sophisticated technology, especially in the years after 1945, farmers, miners, and lumbermen brought a revolutionary and new human ordering to the landscape of the transmontane region.

Although the symbols for the transformation of the interior Northwest are apparent on every hand, none was more spectacular or more environmentally intrusive than the building of dams on the main stem of the Columbia River. Alterations to the riverine landscape originated with the application of steam power to the rail and river movement of commodities, developments that begin innocently but vastly stepped up the pace of change everywhere along the river corridor. The opening of The Dalles-Celilo Canal amidst celebrations and speech making on May 15, 1915, was merely another in a series of efforts to manipulate the contours of the river to meet the marketing and commodity needs of the dominant culture.¹⁰⁶

Both national and international developments were key factors driving the transformation of the Columbia River system: the emergence of electrical power as a source of energy; the stability of the national political economy during the Great Depression; and the logistics of United States foreign policy during the Second World War and after. Out of that welter of demands on the Columbia system, a novel industrial literature emerged to define, explain, and justify the channeling, revetments, canals, and eventually the building of dams across the main stem of the river itself. That new story celebrated the “harnessing” of the “untamed” power of the Columbia, the benefits that would accrue to large numbers of people through the generation of cheap hydropower, the “improved” navigation on the river, and finally, the great expanses of land in the Columbia Basin that would be put to “productive” use through the building of giant canals that would bring water to the “lifeless acres.”¹⁰⁷

¹⁰⁵For a further elaboration of the environmental/ecosystem link between country and city, see William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York: W. W. Norton, 1991).

¹⁰⁶William F. Willingham, *Army Engineers and the Development of Oregon: A History of the Portland District U. S. Army Corps of Engineers* (Washington, DC: General Printing Office, 1983), 36, 74-80 and 92.

¹⁰⁷The best expression of the booster mentality associated with the building of dams on the river is the film, *The Columbia*, produced by the Bonneville Power Administration in 1946. Much of the argument here is based on my essay, “Narrative Form and Great River Myths: The Power of Columbia River Stories,” *Environmental History Review* (forthcoming 1993).

From the time of the great New Deal public works programs of the 1930s until the salmon crisis of recent years, much of the public has viewed that definition of the “working river” in a positive light. The application of engineering skill and scientific expertise, the promoters argued, heralded a bright new future in which the contours of the land would be enhanced to benefit humankind. Journalists like Richard Neuberger singled out for heroic effort the construction workers who braved the heights of Grand Coulee Dam to expand opportunity in “the last great frontier of this country.” The giant Federal projects on the river, Neuberger claimed, would transform an area that supported “desert weeds and bushes, coyotes and rattlesnakes and prairie dogs” into a land of poplar trees, corn fields, farmhouses, and small communities.¹⁰⁸

For Richard Neuberger and others of his age, the natural world of the free-flowing Columbia River had to be put to productive economic use to serve the larger social good. The popular Oregon journalist, state legislator, and United States senator was an exemplary spokesperson for his time and place, expressing attitudes and values that eventually became articulated into public policy. The result was a sustained period of construction on the river and its major arterials that lasted for more than 30 years, activities that transformed the landscape of the Great River of the West, remaking it into a managed, regulated, and highly productive waterway for its industrial users. The environmental writer, Marc Reisner, calls it “the most fateful transformation that has ever been visited on any landscape, anywhere.”¹⁰⁹

The literature on the building of Columbia River dams is but part of a larger body of writing that extolled the efficacy and civic duty to intervene in the natural world for human betterment. And for doubters who raised questions about consequences or environmental effects, the experts assured that technical solutions were at hand. If the dams blocked anadromous fish from spawning grounds, then downstream hatcheries would solve the problem. If the rate of timber harvesting appeared to exceed what were deemed sustainable rates, then hybrid seedlings, eliminating vegetative competition, keeping fire from the forest—or what was termed “intensified forest management”—would enable both sustainable forestry and an increased volume of harvesting. Whether it be the Columbia River, the rich wheat-growing country in the Palouse, or timber stands on the National Forests, engineering and science were widely believed the solution to the seeming contradiction between increased productivity and sustainability. For several decades after the Second World War, few voices were raised in objection to that article of faith.

But in an age where environmental limits are more widely recognized, scientists, policy makers, and others are beginning to understand that streams, forests, and soils do not have an unlimited capacity for increased yield. Awareness is growing that the industrial world has wrought spectacular transformations to ecosystems, some of which people are only beginning to grasp. And it is increasingly apparent that the very symbol of industrial production, the machine, has been an intrusive force both in the natural world and in our economic life. Evidence abounds on every hand of the environmental and economic influence of technology in the fishing industry and in the harvesting of grain crops, as well as in the woods. Although mechanization has been a blessing in alleviating much of the drudgery associated with labor, and increased production has improved the quality of life for many people, it has come with a price.

With the exception of the fur trade, the full force of the market revolution in the Pacific Northwest coincided with the advent of the industrial era. As such, the region’s experiences with human-crafted machines provide fertile ground for studying the environmental consequences of industrial practices. That

¹⁰⁸Richard Neuberger, *Our Promised Land* (1938; Moscow, Idaho: University of Idaho Press, 1989), 353-357.

¹⁰⁹Marc Reisner, *Cadillac Desert: The American West and its Disappearing Water* (New York: Viking Penguin, 1986), 166 and 172. For Neuberger’s enthusiasm for engineering works on the Columbia River, see Paul C. Pitzer, “Visions, Plans, and Realities: A History of the Columbia Basin Project” (Ph.D. dissertation, University of Oregon, 1990).

is especially true for the most important historical industrial undertaking in the Northwest, the logging and milling of timber. Although the machine was an important component in logging operations as early as 1900, it moved into the woods with gusto during the 1930s when operators were switching from steam to the infinitely more mobile gasoline-powered engines. Although steam power was a highly efficient way to transport logs, it was also labor intensive, requiring large crews to fuel the steam boilers on the yarding machines and other equipment.¹¹⁰ In contrast, the introduction of gasoline-driven yarding machines, the development of the caterpillar tractor, and the adoption of the log truck vastly increased the ability to move a huge volume of timber. Those devices also narrowed the technological gap between logging and sawmilling operations. Finally, the widespread use of the chain saw by 1950 served as the capstone to a technological environment that was far removed from the days of bull teams, steam-powered donkey engines, and logging railroads. The production statistics speak for themselves.

An environmental side to that equation is obvious. Logging with bull-teams and horses was relatively benign to forest environments east and west of the Cascade Range. But the introduction of the steam donkey, first developed in the redwood and Douglas-fir country and quickly adapted to pine logging, greatly increased human-induced disturbance to eastside forest environments. In fact, because of the easier terrain, pine loggers may have more readily adopted mechanized equipment. The coming of the machine to the woods of the interior Northwest, therefore, had both economic and ecological dimensions: it speeded the rate of timber harvesting and led to the rapid growth of communities; and it contained the seeds of social dislocation and environmental disruption when the timber was gone. It should also be remembered that logging practices on the private timberlands of Oregon and Washington had no restraints until the Second World War (and then they were minimal and usually went unenforced).

To accommodate the use of the practical and cost-effective steam and gasoline-powered machines, loggers and foresters developed new harvesting procedures—clearcutting the entire area within reach of the yarding machine's system of cables. Cutting practices, in effect, were adapted to technology. Indeed, a good case can be made that the machine and the markets that made its use profitable became the chief determinant in reshaping the forest environment. Science, insofar as it was used to answer to the needs of the machine, became an ally of production and capital markets.¹¹¹

The new postwar marketing conditions, which were unlike anything the industry had ever experienced, helped spur further technological innovation. Whereas the lumberman's chief complaint before the Second World War was overproduction—the dumping of too much timber on a saturated market—by the close of the 1940s producers were struggling mightily to keep pace with demand. Those new marketing arrangements placed a premium on the most modern and productive forms of technology. The consequences were extensive alterations to forest landscapes everywhere, and widespread and unprecedented increases in disturbances to forest ecosystems. By 1950, most scientists and public officials were treating the forest as a thoroughly commodified part of nature. The complex and extensive ecosystems of plant life, animals, and microorganisms were simplified to quantifiable board-feet measurements to satisfy the needs of the hour.

Nothing is new in the commodity calculus attached to natural resources; viewing forests, rivers, grasslands, and mineral-rich mountain slopes for their commodity value has a long and hallowed tradition in American history. To be sure, treating complex ecosystems as goods to be modified at will or brokered in the marketplace has contributed to problems with our rivers and woodlands, but there is much more to the story. Since the coming of Euro-Americans to the Pacific Northwest, the dominant culture has played out a production-driven end game based on the assumption that more fish could be pumped from the

¹¹⁰For a discussion of the reduction in the labor force during the latter 1940s, see Robbins, *Hard Times in Paradise*, 130-131.

¹¹¹For a more detailed discussion of this argument, see the author's essay, "The 'Luxuriant Landscape': The Great Douglas Fir Bioregion," *Oregon Humanities* (Winter 1990), 2-7.

river, more kilowatt hours of electricity could be generated from dams, and more board feet of timber could be grown in the forests if **only** rational engineering and scientific approaches were brought to the task.

Today, mounting evidence tells us that something has gone amiss, that we cannot have unlimited hydropower production and fish too, that we cannot endlessly manipulate forest ecosystems to produce more wood fiber. The best of the present work in the ecological sciences, much of it carried on in the region's land-grant colleges and in range and forest research stations, is based on a sound reckoning with the environmental changes that have occurred in the last century. Scientists are beginning to understand the wisdom of forester Edward I. Kotok, who cautioned nearly 50 years ago that too much emphasis was being placed on the end product rather than on "the maintenance or creation of a healthy, well-balanced biological complex that by its nature is conducive to favorable vegetative growth, water relations, and the support of animal life."¹¹²

In terms of places long occupied by humans, the landscape of the Pacific Northwest is a short-lived enterprise, say 20,000 years as a median benchmark. As a place dominated by Euro-Americans, the time frame narrows to roughly 150 years; for the intermontane Northwest, a century. East of the Cascade Range—as in the more westerly country—complex ecosystems have been drastically modified and simplified. In the arid country of the Inland Empire, cheatgrass and other annual brome grasses have replaced bluebunch wheatgrass on land used exclusively for grazing. Elsewhere on the plateaus and gentle slopes of the Palouse, a monoculture crop, wheat, has replaced everything else. And in the Blue Mountains to the south, true fir and Douglas-fir have replaced some of the area once covered by great stands of ponderosa pine.¹¹³

With the exception of drought, windstorm, and lightening-caused fires, the spectacular changes to the landscape of the interior Northwest during the last century have been human-induced. The striking historical feature of this story is the abbreviated number of years in which those alterations have taken place, especially the accelerating rate of modification during the last few decades. As public citizens, we all have much to learn about the history of that complex ecological and economic web that is part of our daily lives.

¹¹²Kotok, "The Ecological Approach to Conservation Programs," 471.

¹¹³Buechner, "Some Biotic Changes in the State of Washington," 169; Boyd E. Wickman, Forest Health in the Blue Mountains: The Influence of Insects and Disease, USDA Forest Service, PNW Research Station, General Technical Report, PNW-GTR-295 (March 1992), 2; and Blue Mountains Natural Resources Institute Annual Report, USDA Forest Service, PNW Region (October 1, 1991 - September 30, 1992), 3.

Appendix A--Population of eastern Oregon counties

	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970
Baker	2,804	4,616	6,764	15,597	18,076	17,929	16,754	18,297	16,715	17,295	14,919
Crook			3,244	3,964	9,315	3,424	3,336	5,533	8,991	9,430	9,985
Deschutes						9,622	14,749	18,631	21,812	23,100	30,442
Gilliam			3,600	3,201	3,701	3,960	3,467	2,844	2,817	3,069	2,342
Grant	2,251	4,303	5,080	5,948	5,607	5,496	5,940	6,380	8,329	7,726	6,996
Harney			2,559	2,598	4,059	3,992	5,920	5,374	6,113	6,744	3,442
Hood River					8,016	8,315	8,938	11,580	12,740	13,395	13,187
Jefferson						3,211	2,291	2,042	5,536	7,130	8,548
Klamath			2,444	3,970	8,554	11,413	32,407	40,497	42,150	47,475	50,021
Lake		2,804	2,604	2,847	4,658	3,991	4,833	6,293	6,649	7,158	6,343
Malheur			2,601	4,203	8,601	10,907	11,269	19,767	23,223	22,764	23,169
Morrow			4,205	4,151	4,357	5,617	4,941	4,337	4,783	4,871	4,465
Sherman			1,792	3,477	4,242	3,826	2,978	2,321	2,271	2,446	2,139
Umatilla	2,916	9,607	13,381	18,049	20,309	25,946	24,399	26,030	41,703	44,352	44,923
Union	2,552	6,650	12,044	16,070	16,191	16,636	17,492	17,399	17,962	18,180	19,377
Wallowa			3,661	5,538	8,364	9,778	7,814	7,623	7,264	7,102	6,247
Wasco	2,509	11,120	9,183	13,199	16,336	13,648	12,646	13,069	15,552	20,205	20,133
Wheeler				2,443	2,484	2,791	2,799	2,974	3,313	2,722	1,849

Appendix B--Population of eastern Washington counties

	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970
Adams				2,098	4,840	10,920	9,623	7,719	6,209	6,584	9,929	12,014
Asotin				1,580	3,366	5,831	6,539	8,136	8,365	10,878	12,909	13,799
Benton						7,937	10,903	10,592	12,035	51,370	62,070	67,540
Chelan					3,070	15,104	20,906	31,634	34,412	39,301	40,744	41,355
Columbia			7,103	6,709	7,128	7,042	6,093	5,325	5,549	4,860	4,569	4,439
Douglas				3,161	4,926	9,227	9,392	7,561	8,651	10,817	14,890	16,787
Ferry					4,562	4,800	5,143	4,292	4,701	4,096	3,889	3,655
Franklin				696	486	5,153	5,877	6,137	6,307	13,563	23,342	25,816
Garfield				3,897	3,918	4,199	3,875	3,662	3,383	3,204	2,976	2,911
Grant						8,698	7,771	5,666	14,668	24,346	46,477	41,881
Kittitas				8,777	9,704	18,561	17,737	18,154	20,230	22,235	20,467	25,039
Klickitat	230	329	4,055	5,167	6,407	10,180	9,268	9,825	11,357	12,049	13,455	12,138
Lincoln				9,312	11,969	17,539	15,141	11,876	11,361	10,970	10,919	9,572
Okanogan				1,467	4,689	12,887	17,094	18,519	24,546	29,131	25,520	25,867
Pend Oreille							6,363	7,155	7,156	7,413	6,914	6,025
Spokane	996		4,262	37,487	57,542	139,404	141,289	150,477	164,652	221,561	278,333	287,487
Stevens		734	1,245	4,341	10,543	25,297	21,605	18,550	19,275	18,580	17,884	17,405
Walla Walla	1,318	5,300	8,712	12,224	18,680	31,931	27,539	28,441	30,547	40,135	42,195	42,176
Whitman			7,014	19,109	25,360	33,280	31,323	28,014	27,221	32,469	31,263	37,900
Yakima		432	2,811	4,429	13,462	41,709	63,710	77,402	99,019	135,723	145,112	144,971

Biotic and Abiotic Processes of Eastside
Ecosystems: The Effects of Management on Plant
and Community Ecology, and on Stand and
Landscape Vegetation Dynamics

by

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INTRODUCTION

Changing climates affect the distribution and composition of plant species indigenous to eastside forest, shrubland, grassland, and woodland ecosystems. Analysis of paleobotanical data from pollen records and woodrat middens describe major changes in vegetation and vegetation patterns on the east side in the last 20,000 years.

The kinds of plant communities in eastside ecosystems today are summarized. The premanagement era is the basis for describing the vegetation structure, composition, and patterns. Primary disturbances (fire, grazing, insects, diseases) that modified the vegetation are related to successional processes and pathways induced by these natural disturbances. These disturbances are not considered destructive; they altered plant communities and affected ecosystem function.

With settlement and increased modification of the landscape by Euro-Americans, natural processes were altered as land management activities intensified and periodic burning by natural fire was curtailed. Major management practices that have interacted with successional processes, landscape patterns, structures, and patch sizes and shapes are addressed. Eastside landscape patterns of the present day are contrasted with those of the recent past (last 100 years) and the prehistoric past (last 20,000 years), to emphasize the changing nature of eastside ecosystems as a result of disturbances. Stand dynamics, complex plant interactions, and the effects of management practices on vegetation development are emphasized. Degraded sites need to be restored to compositions and structures that will enhance biological diversity and ecosystem function across eastside landscapes.

LATE QUATERNARY PRECURSORS: THE LAST 20,000 YEARS—AN OVERVIEW

Late Pleistocene Environments

The striking vegetational shifts described for the Pacific Northwest during the last 20,000, 10,000, or 1000 years are not unusual. In fact, no vegetation on earth has escaped the repeated stress of glacial climates and interglacial adjustments or the short, sharp climatic shifts during each period. With each episode, species displaced by climate, ice, water, and competition responded through growth form, migration, or selection—or faced local extinction. At various paces in different places, species repeatedly abandoned and then reclaimed the same terrain, but not always with the same associates.

The last glaciation brought Laurentide or Cordilleran Ice sheets to Washington, Idaho, and Montana, and ice caps grew in the larger ranges (Waitt and Thorson 1983). The largest area of ice south of the continental ice sheets covered the Yellowstone Plateau; other ice caps formed over the Bitterroot and Sawtooth ranges, and along the spine of the Cascade Range. Other ranges supported small ice caps or cirque and valley glaciers that receded to near present limits by 10,000 B.P. Re-advances of alpine glaciers and downslope retreat of the upper tree line mark cold, moist episodes of the Holocene (Davis 1988).

Pleistocene lakes drowned vast areas of the Northwest and Great Basin and, along with glaciers, acted as barriers to plant movements. The lakes may also have contributed to restriction or demise of populations by their growth and by catastrophic draining. With final desiccation, plants colonized fine-grained substrates that had accumulated over thousands of years. Some lake floors (such as Glacial Lake Missoula) were probably stabilized rapidly by grasses and sagebrushes, whereas others (such as Pluvial Lake Bonneville) still return windborne sediment to surrounding ranges and adjacent valleys. The late histories of these two lakes illustrate the rapidity and intensity with which brief climatic variability altered the Pleistocene landscape on a grand scale.

Along the margin of continental glaciers in Washington, Idaho, and Montana, proglacial lakes grew in ice-dammed drainages. The largest of these, Glacial Lake Missoula, formed when ice extended southward in the Purcell Trench and blocked the Clark Fork Valley with a 600-meter-high ice dam at the Montana-Idaho border. Rivers and melting glaciers fed the resulting lake until it spread over 3000 km², with a volume near that of Lake Ontario. Faint wave-formed beaches still mark the hillsides to 290 m above Missoula, Montana. Although estimates of the number vary, periodic catastrophic outburst floods or jokulhaups, began with failure of the ice-dam. With each "Spokane Flood," as much as 2150 km³ of water poured through the breach, Pend Oreille Lake, and the Spokane Valley. Icy torrents, hundreds of meters deep, and tens of kilometers wide, then raged across central Washington, violating drainage divides, stripping Palouse loess, and raising gigantic basalt blocks from their beds. Washington's distinctive scablands are the product of some of the greatest floods known from the geologic record; the last of these occurred about 13,000 B.P. (Waitt 1985).

Volcanic ash layers (tephra) that allow precise correlation of vegetational events within the northern Rocky Mountains (Carrara 1989) and far beyond will prove the greatest asset of this region in deciphering patterns of Quaternary vegetation history. Multiple eruptions of Cascade volcanoes such as Mount Mazama (Crater Lake), Oregon (Bacon 1983), and Glacier Peak (Foit and others, in press; Mehringer and Foit 1990; Mehringer and others 1984), and Mount St. Helens, Washington (Crandell 1987, Mullineaux 1986, Yamaguchi and others 1990), cast long shadows downwind (fig. 1). Tephra of their individual eruptions may be distinguished and correlated by stratigraphic position, radiocarbon or tree-ring age, mineral suites, and glass chemistry. Mazama and Glacier Peak tephra appear in lake sediments in distant Montana (fig. 2). These two tephras are time stratigraphic markers important in correlating vegetation changes from the Cascades all the way to Glacier and Yellowstone National Parks (Carrara 1989; Whitlock, in press).

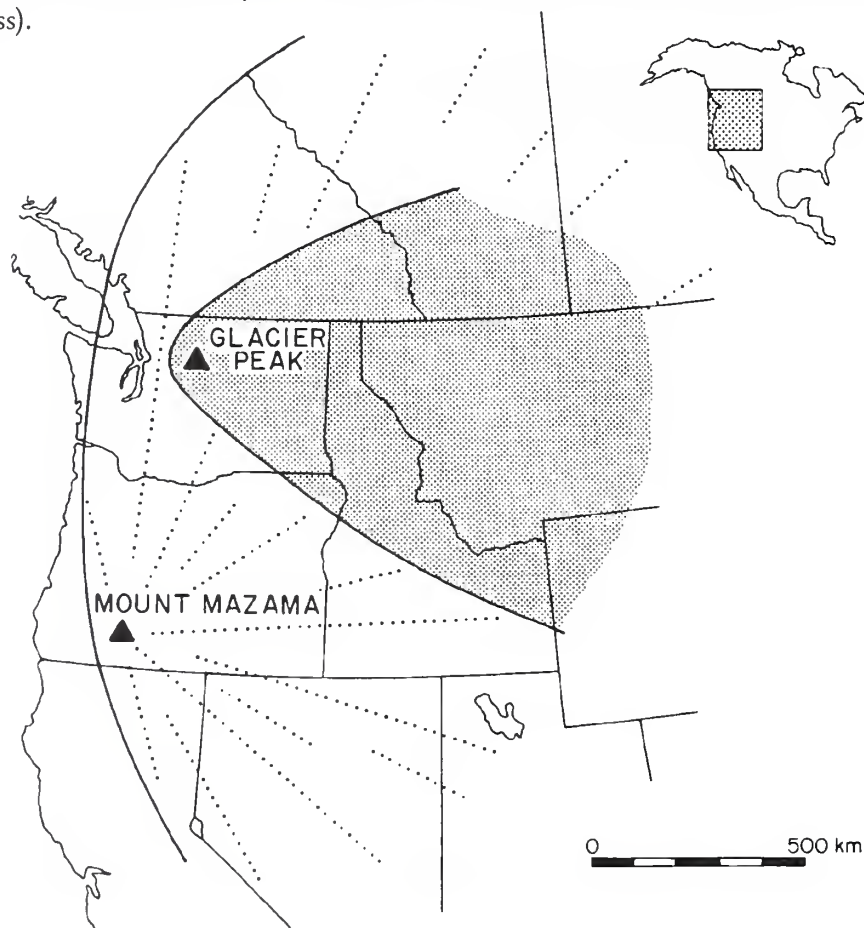


Figure 1. Distribution of Glacier Peak (11,250 B.P.) and Mazama (6850 B.P.) tephras (Blinman and others 1979).

Western Washington

Vegetation and climate—Because the eastside's climatic patterns are shaped over the Pacific Ocean and move eastward, primary features of climate-induced vegetation history are related on both sides of the Cascades. With one exception, published eastside late-Quaternary fossil-plant sequences are younger than 13,000 B.P. West of the Cascades, pollen records are old enough to be useful in evaluating full-glacial and interstadial conditions, and they frequently show more detail in the number of tree species and in the order of their arrivals or departures. In the Puget Trough, for instance, fossil sequences reveal vegetation of the coldest episodes south of continental glaciers, as well as the northward progress of developing postglacial forests. By contrast, eastside sites are scattered and forest is discontinuous at low to middle elevations (Franklin and Dyrness 1973, fig. 27). On the east side, causes of latitudinal or elevational differences in species's ranges or associations must be evaluated by details of specific, often geographically and ecologically isolated, data and by recognizing common patterns in fossil records from vastly different present plant communities.

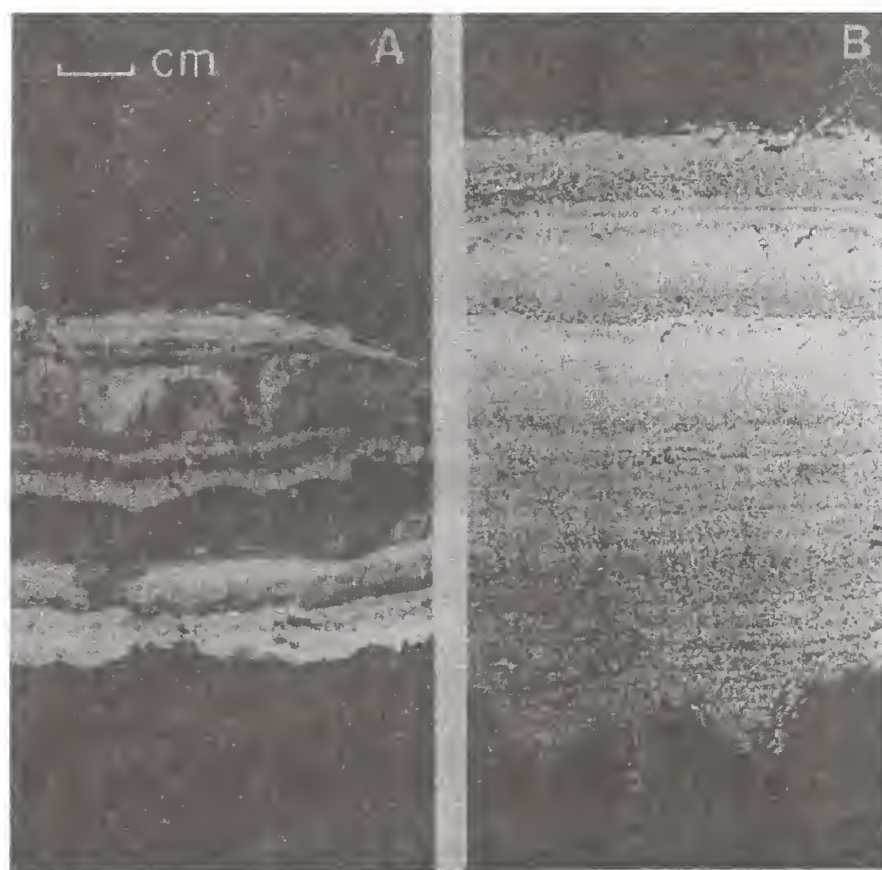


Figure 2. Glacier Peak (A) and Mazama (B) tephras from Lost Trail Pass Bog, Montana.

The following brief description highlights the main features of western Washington's late-Quaternary vegetation history to provide a broader chronologic and paleoclimatic context for discussion. The emphasis follows Whitlock (1992), who reviewed and explained the fossil records by reference to recent climatic models (COHMAP Members 1988; Thompson and others, in press).

During the last glaciation (20,000-14,000 B.P.), continental ice sheets cooled the middle latitudes, and winter storm tracks shifted south, leaving the Northwest cold and dry. Even the western Olympic Peninsula lowlands sported vegetation resembling today's cool, maritime, subalpine parkland of the Olympic Mountains. In the lowlands, sparse trees included spruce (*Picea* spp.), pines (*Pinus* spp.), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) and western hemlock (*T. heterophylla* (Raf.) Sarg.). Treeless, alpinelike communities occupied

glacial margins and exposed sites. With a warming sea surface after 15,000 B.P., an ameliorated coastal climate enhanced the success of spruce, alder (*Alnus* spp.), and western hemlock.

Dominance of grass (Gramineae), sedge (Cyperaceae, and sagebrush (*Artemisia* spp.) pollen with macrofossils of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) suggest that the Puget Trough lowlands sustained open alpine parklands (fig. 3). Precipitation was much reduced, and mean annual temperatures were perhaps 57° C cooler than today. The most likely modern analog is found east of the Cascades in the alpine of the northern Rocky Mountains.

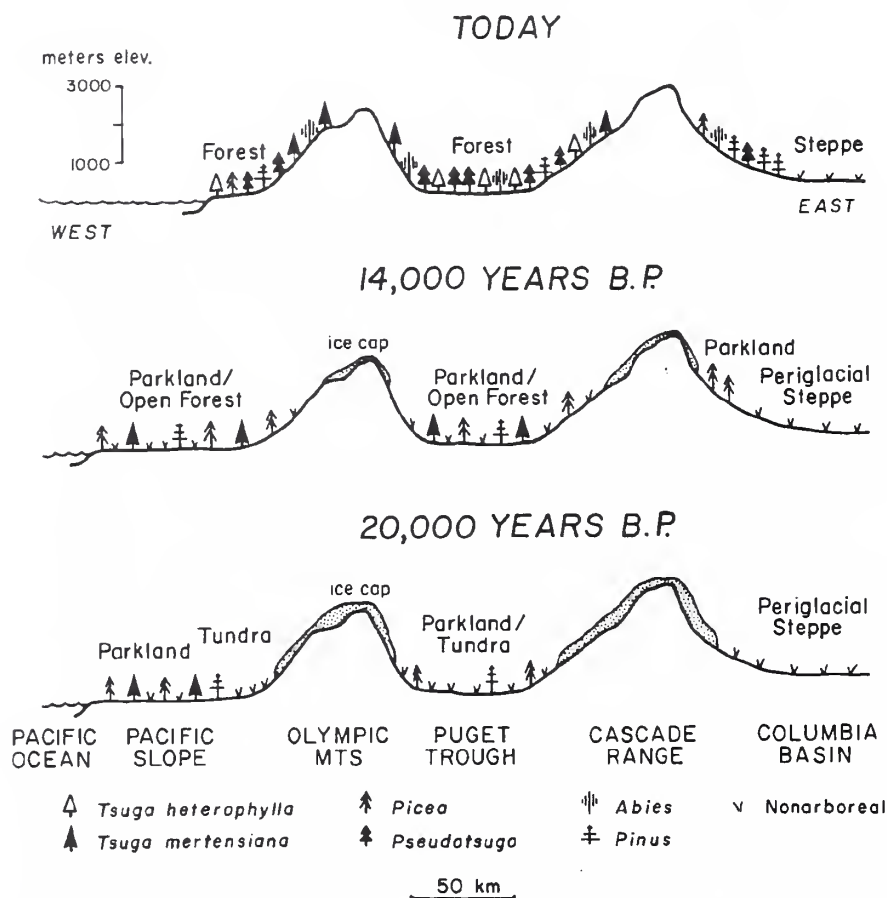


Figure 3. Schematic transect across southwestern Washington shows distribution of ice and dominant vegetation today, at 20,000 B.P. during the height of mountain ice caps (Evans Creek Stade), and at 14,000 B.P. (Vashon Stade) during the maximum advance of Cordilleran glaciers into the Puget Trough north of this transect (after Barnosky 1984, Whitlock 1992).

Between 14,000-10,000 B.P., deglaciation and appearance of temperate taxa marked the transition from the late glacial to the Holocene. Precipitation increased and annual temperatures rose to near modern values by the end of this period. New species forming transitional communities without modern analogs filled the freshly deglaciated terrain of the Puget Trough. Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), the most successful invader, was soon joined by alders, spruce, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and western hemlock. Just south of the ice sheet, temperate, low-elevation elements first mixed with, then succeeded montane species.

Early Holocene introduction of xerothermic communities began about 10,000 B.P., when greater summer radiation brought warmer, drier summers to the Northwest. Whitlock and Bartlein (in press) suggest that summer dry areas of today were even drier about 9000 B.P., and summer wet areas (for example, the Southwest United States watered by the Mexican monsoon) were wetter than today. Their notions for the Northwest find support in record after record from both sides of the Cascades. For example, between

9500 and 5000 B.P., the fossil pollen sequences from the Olympic Peninsula and Puget Trough show more Douglas-fir and bracken fern (*Pteridium aquilinum* (L.) Kuhn.) than today. Also, local prairies expanded, and sediments of this period contain abundant charcoal that attests to the increased importance of wild-fires. In the southern Puget Trough, Washington, the late glacial forest gave way to open forest or savannah, similar to the historic vegetation of the Willamette Valley, Oregon.

After about 5400 B.P., increasing precipitation and rising water tables are again apparent on both sides of the Cascades. In western Washington, mesophytic taxa such as western redcedar (*Thuja plicata* Donn ex D. Don), western white pine (*Pinus monticola* Dougl. ex D. Don), and western hemlock assumed more importance, prairies became smaller, and modern plant associations began to emerge.

The highlights of western Washington's vegetation history for the last 20,000 years (Whitlock 1992) give a general idea of major climatic episodes and their influences (fig. 3). These generalities, however, often come from detailed data illustrating the continual short, sharp climatic shifts that produced rapid changes in the Northwest's vegetation directly (for example, through soil moisture) or indirectly (through fire and disease).

The Eastside Story

Fossil records of late-Quaternary vegetation east of the Cascades have been the subject of sporadic study since the 1930s, when Henry P. Hansen (1947) pioneered pollen analysis in Washington and Oregon. His studies showed that the Northwest's vegetation had been dynamic throughout the late-Quaternary in response to climate, volcanic eruptions, and fire. Instability and change were the norm. Over the past decade, several reviewers have compiled what is known about the late-Quaternary fossil pollen and plant macrofossils of the region and have discussed the chronologies and causes of vegetation change in the interior Northwest and adjacent areas (Barnosky 1985; Barnosky and others 1987; Chatters, in press; Heusser 1985; Mehringer 1985; Whitlock 1992).

Familiar eastside plant associations in steppe, woodland, montane and moist maritime forests, and alpine areas consist of species that have responded independently to the varying intensities of numerous glacial-interglacial cycles. In each cycle, brief warmth punctuated long, cold intervals, and plants responded to the vagaries of climate, dispersal potential, competition, selection, soils, topography, volcanic eruptions, fire, chance—and, more recently, ever increasing numbers of people. With few exceptions, details of past species distributions and associations are poorly understood in this region. Evidence is mounting, however, for the general features of late-Quaternary vegetation history (fig. 4), for their chronology, and for their causes.

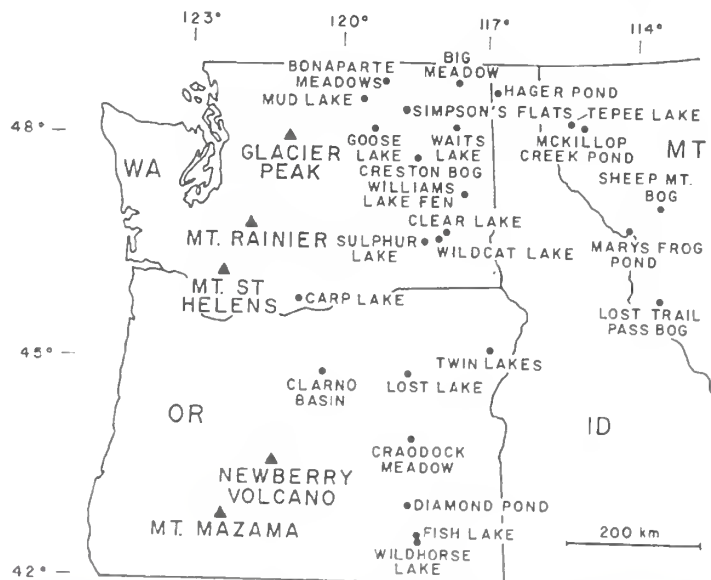


Figure 4. Important eastside study sites for fossil pollen and woodrat middens.

Steppe, eastern Washington—Although the northwestern United States is noted for its remarkably diverse conifer forests, steppe covers more area than all forest types east of the Cascades in Washington and Oregon (Franklin and Dyrness 1973, fig. 27). Grassy communities extend upward from shadscale associates in the hot, dry interior basins, through sagebrush and western juniper (*Juniperus occidentalis* Hook.) woodlands, ponderosa parklands, the lush Palouse grasslands of eastern Washington, and mountain grasslands of southeastern Oregon. Between 20,000 and 4000 years ago, steppe was even more widespread. In fact, fossil pollen or woodrat (*Neotoma* spp.) midden macrofossils from the Great Basin (Thompson 1990, Wigand and Nowak 1992) to southeastern Idaho (Beiswenger 1991) to eastern Washington (Barnosky 1985) and Oregon (Mehring 1985) attest to expansion of steppe under cold continental conditions coincident with the last glaciation and continued importance of steppe with high temperatures of the early and mid-Holocene.

From 20,000 to 12,000 B.P., south of continental ice and below the mountain glaciers, cold steppe typified much of the northwestern interior of the United States. Carp Lake, southwestern Columbia Basin, Washington, holds sediments spanning parts of the past 33,000 years (Barnosky 1985). Sagebrush and grass pollen dominate this record. Slightly more conifer pollen before 23,000 B.P. suggests temperate steppe, but full-glacial temperatures too cold for trees apparently produced cold sagebrush steppe. According to Whitlock (1992), this sequence indicates colder and drier conditions from 23,000 to 10,000 B.P., with the lower tree line higher than today.

All other fossil pollen localities from eastern Washington are younger than Carp Lake because they lay in the path of glaciers or scabland floods until after 13,000 B.P. Through the oldest date to < 13,000 B.P., without exception, they show initial dominance of sagebrush and grass pollen. Sites now well within areas dominated by conifers continue to show large values of sagebrush, grass, and chenopod pollen until some time between the fall of Mazama tephra (6850 B.P.) and about 4000 B.P. For the pre-Mazama period, the most detailed analyses come from Williams Lake Fen.

At 635 m, Williams Lake Fen is located in a flood-formed plunge pool between Badger and Williams Lakes, 20 km south of Cheney, Washington. Its present position is within communities dominated by ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) where it meets *Artemisia tripartita*-*Festuca* and *Festuca*-*Rosa* communities that spread to the west and south (Daubenmire 1970). Initial coring and analyses established the site's potential and indicated grass and sagebrush dominance for most of the Holocene. Ponderosa pine was not important here until after 4000 B.P. (Nickmann 1979).

Recently, larger and deeper cores and additional analyses established details of late-glacial tephrochronology and the sequence of vegetation that followed the last of the Lake Missoula floodwaters through the Cheney-Palouse scablands. These cores (Mehring, unpub.), dating from about 12,700 B.P., bottomed in flood gravels at 10.83-m sediment depth. They hold two layers of Mazama tephra separated by 9 cm of lake deposits and five late glacial tephra—one from an unknown source (the 10,600 B.P. "Tawny Ash"), two from Glacier Peak (11,250 B.P.), and two (one above and one below the Glacier Peak tephra) from Mount St. Helens (Foit and others, in press). Selected ratios and percentages illustrate the fossil pollen sequence and suggest trends in past vegetation and climate.

Selected curves of 64 analyses of pre-10,000 B.P. sediments from Williams Lake Fen reveal details of events related, through climate, to fluctuating lake level, fire frequency, and vegetation. Large values in pollen curves of two kinds of lake-edge plants, sedge and waterlily (Nymphaeaceae) (fig. 5), indicate shallow water nearer the coring site. Their largest pre-Mazama values center on 9.85-m depth, corresponding to large charcoal concentrations. Three trends are evident before 10,000 B.P. (figs. 5, 6, 7).

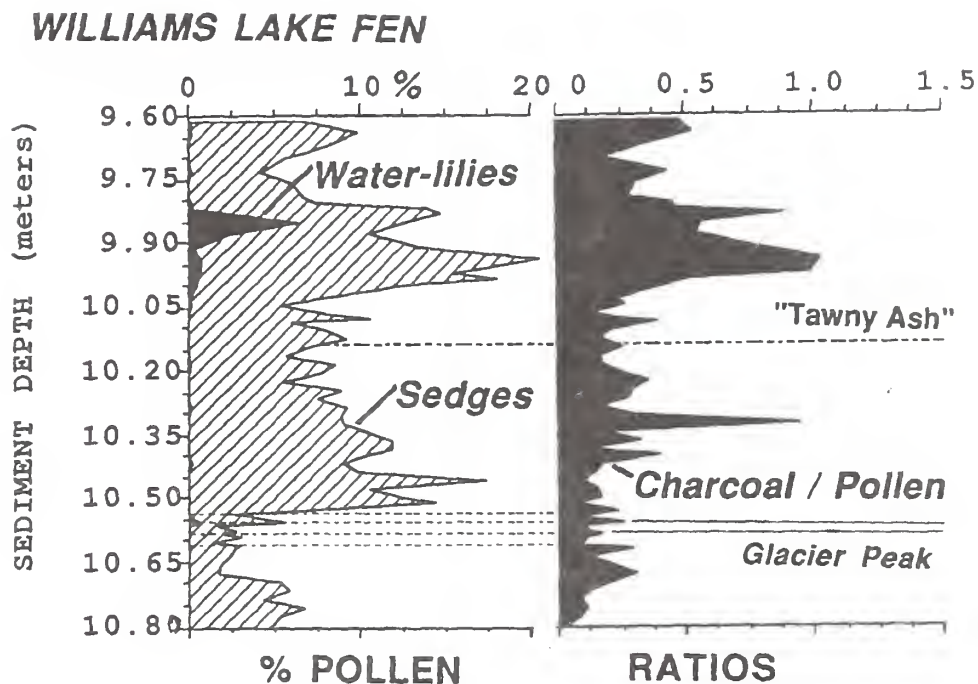


Figure 5. Percentages of pollen types showing correspondence between shallow-water indicators and charcoal abundance.

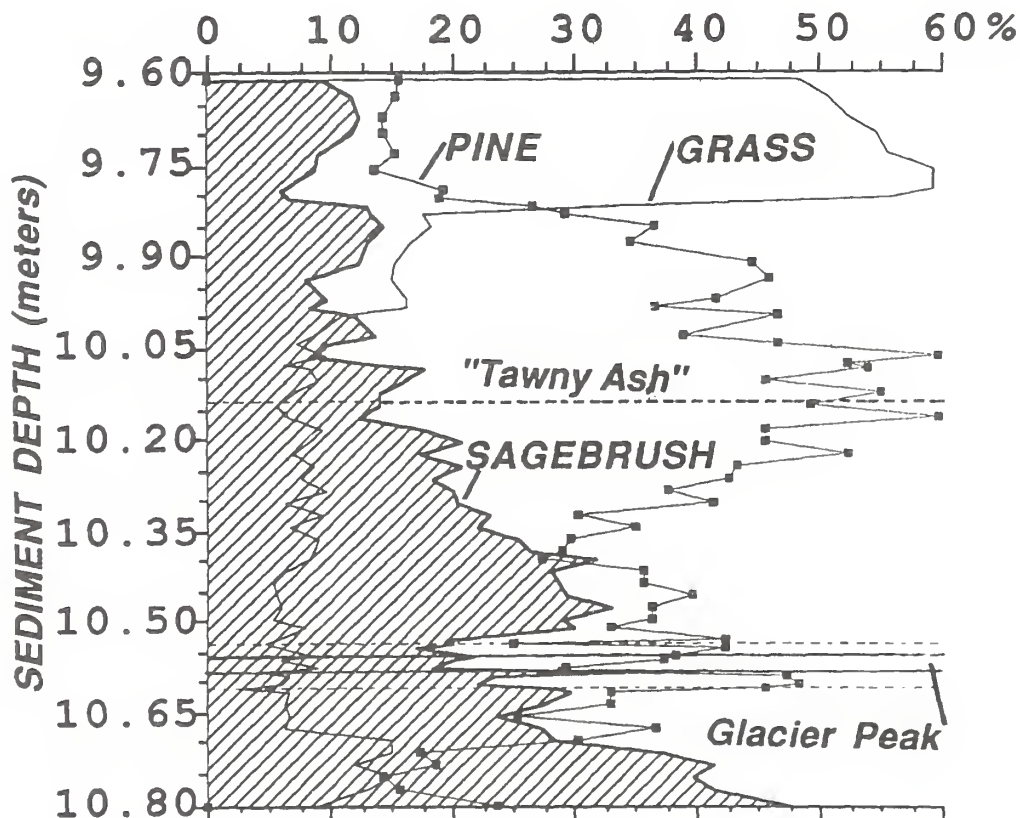


Figure 6. Percentages of sagebrush, grass, and pine pollen at Williams Lake Fen dating from about 12,700 after the last Missoula flood to about 10,000 B.P. after the decline of the late-glacial pine pollen event. "Tawny Ash" dates to 10,600 B.P.

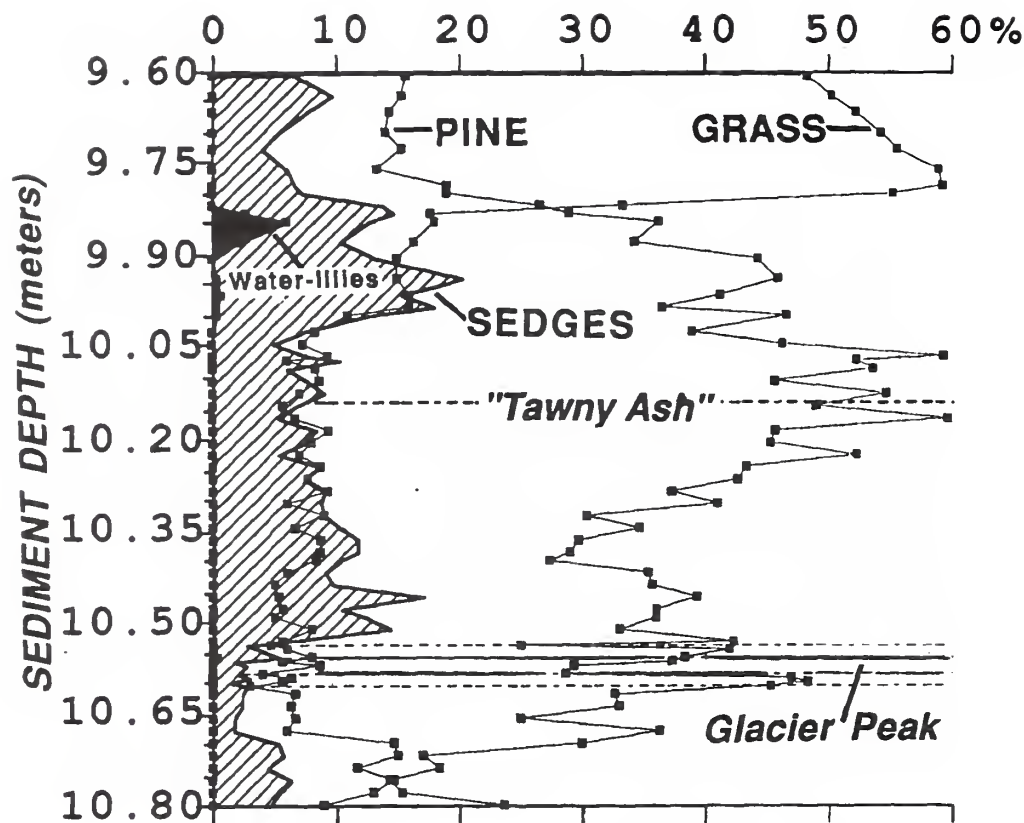


Figure 7. Percentages of water-lily and sedge pollen (shallow water-indicators) at Williams Lake Fen, compared with the grass and pine pollen curves. "Tawny Ash" dates to 10,600 B.P.

- Smallest pollen influx, largest percentages of spruce and birch pollen, and primary importance of sagebrush pollen suggest cold continental conditions from about 12,700 to 12,000 B.P.
- From about 12,000 to 11,000 B.P., grass and sagebrush pollen vary but pine pollen generally increases.
- The period from 11,000 to 10,000 B.P. shows marked fluctuations and the largest conifer pollen values (perhaps indicated a Younger Dryas-like oscillation) (Engstrom and others 1990, Zhisheng and others 1993).

After the second Glacier Peak ashfall, declining sagebrush and grass counts, and large pine pollen counts, indicated significant and rapid expansion of conifers, followed by their catastrophic decline (from 60 to 14 percent of total terrestrial pollen) and grass dominance (50 to 60 percent). The pine pollen peak centered on 10,600 B.P. result from more than one invader because it includes both haploxylon (white pines such as limber (*P. flexilis* James) and whitebark (*P. albicaulis* Englem.) and diploxylon types (such as lodgepole and ponderosa pines), as well as continued small amounts of spruce and fir pollen.

Perhaps a reliable snow pack, sufficient to protect young conifers and shorten the period of low late summer and fall soil moisture, encouraged rapid expansion of mixed conifers at lower elevations in the eastern Cascade foothills and on favorable sites throughout eastern Washington. Whatever the reason, climatic conditions that had brought success to conifers after the fall of Glacier Peak tephra changed suddenly.

Pollen of aquatic plants shows that shrinking lakes accompanied diminishing conifers. For example, between 9.8 and 10 m (centered on 9.85 m), indicators of shallow, warm water first appear in abundance. These indicators include the only pre-Mazama concentrations of water-shield (*Brasenia* sp.) pollen, the

largest percentages of sedge and cat-tail (*Typha* spp.) pollen, and waterlily (*Nuphar* sp.) pollen and leaf hairs. Large charcoal values indicate increased fire frequencies or intensities.

By about 10,000 B.P., grassland must have dominated more of eastern Washington than it does today. At Williams Lake Fen, grasslands apparently persisted for the next 3000 years, with few differences by comparison with the preceding 3000 years. Slight increases in pollen percentages of saltbushes (*Atriplex* spp.) and (*Sarcobatus* spp.), sagebrushes, and other composites (compositae), however, indicate probable upwind expansion of more xeric steppe and newly exposed margins of shrinking lakes and ponds before the eruption of Mount Mazama.

The shift from conifer to grass pollen dominance at Williams Lake Fen about 10,200 B.P. is perhaps the most striking change recorded in this region's record of postglacial vegetation. At Wildcat Lake (Mehringer, unpub.) and Goose Lake (Nickmann and Leopold 1985), the shift from conifer to grass pollen dominance was similarly dated and as clearly revealed by close sampling. Hebda (1982) saw the same pattern in the southern interior of British Columbia where he reconstructed the post glacial vegetation sequence, emphasizing grassland, as follows:

- ❑ 13,000 to 12,000 B.P., open pioneer treeless vegetation;
- ❑ 12,000 to 10,000 B.P., mixed conifer forest invaded, established and declined;
- ❑ 10,000 to 8000 B.P., xeric grassland maximum;
- ❑ 8000 to 4500 B.P., mesic grassland, extent partially reduced by Douglas-fir and ponderosa pine; and
- ❑ 4500 to 3000 B.P., minimum grassland, maximum forest expansion into former grassland, and beginning of recent conditions of climate and vegetation.

From study of Wildcat Lake cores, Davis and others (1977) described effects of historic disturbance reflected in the changing pollen of aquatic, weedy, and exotic species, and response of algae to erosion and organic enrichment. Blinman and others (1979) described details of the Mazama tephra sequence. Since then, Wildcat Lake was cored again through 5 m of water to a sediment depth of 27.39 m (Mehringer, unpub.). Like Williams Lake Fen, the basal date is about 12,700 B.P., and Glacier Peak tephra allow exact correlation. Unlike sites farther from eastern Washington's arid core, however, Wildcat Lake has remained in steppe since at least 10,000 B.P. Today it lies within the *Agropyron-Festuca* grassland bounded on the west by the warmer and drier *Artemisia-Festuca* and on the east by the more mesic *Festuca-Rosa* zone (Daubenmire 1970).

Ternary plots (fig. 8) of grasses, sagebrushes, and saltbushes separate various steppe communities, as judged from plots of their fossil pollen over the last 5700 years. The same technique is helpful in distinguishing fossil pollen assemblages from Wildcat Lake (fig. 9) and, together with other data, lead to the following conclusions (fig. 10):

TERNARY PLOTS OF FOSSIL POLLEN (0-5700 B.P.)

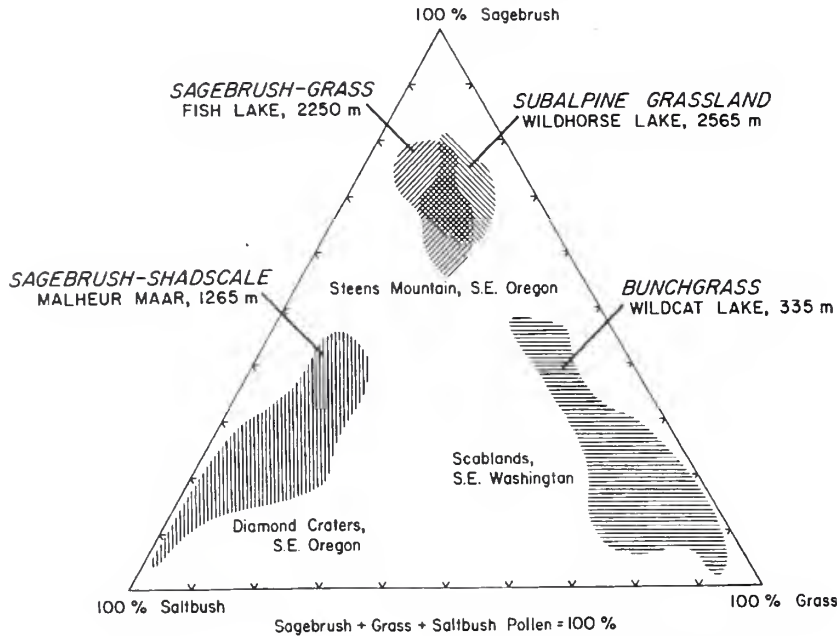


Figure 8. Ternary plots of fossil pollen from four steppe communities in eastern Oregon and Washington. Relative abundances of saltbushes (including *Sarcobatus*), sagebrushes, and grasses distinguish steppe associations that most often produce monotonous Holocene pollen profiles dominated by nonarboreal pollen and by pine pollen transported long distances (Mehringer 1985).

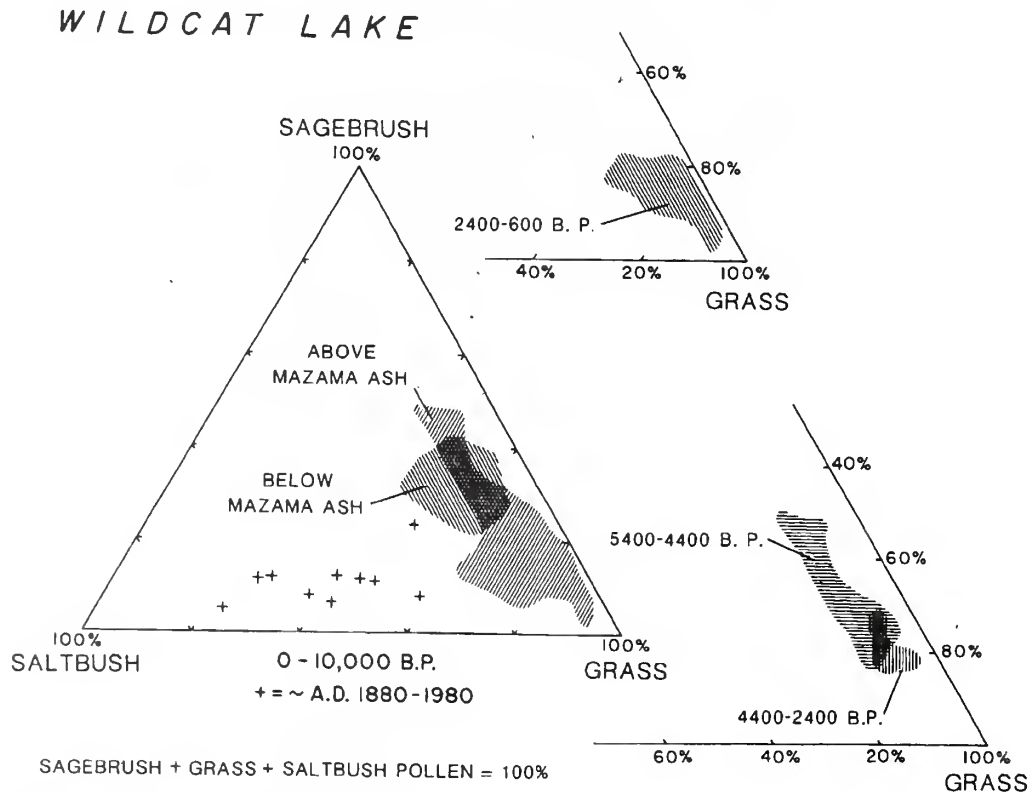


Figure 9. Ternary plots of pollen from saltbushes, sagebrushes, and grasses from selected periods of the last 9000 radiocarbon years from Wildcat Lake, Washington. Note that the largest grass values occur within the last 2400 years and that samples of the past 100 years (+) are distinctive (Mehringer 1985).

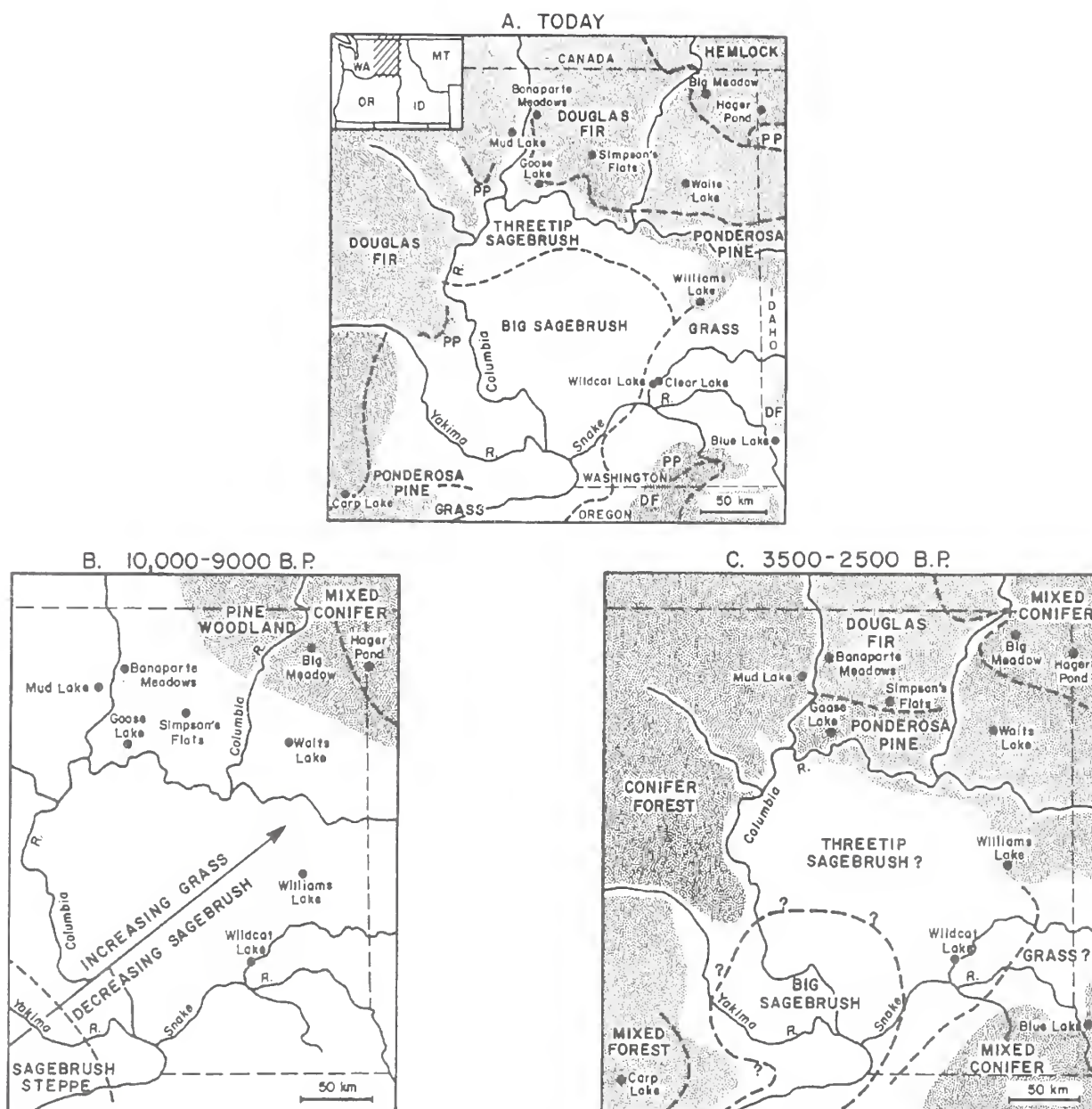


Figure 10. Today's steppe-woodland border and estimates of its position 10,000 to 9000 B.P., when steppe replaced conifer woodlands and forest, and 3500 to 2500 B.P., when conifer woodlands probably advanced into steppe all along eastern Washington's steppe-woodland ecotone (after Chatters, in press; Chatters and others, in press).

- ☐ Pre-Mazama samples (9000 to 7000 B.P.) fall within a cluster in which both grass and sagebrush pollen are important. Sagebrush pollen values place these samples in big sagebrush (*Artemisia tridentata* Nutt.) communities to the west.
- ☐ Sagebrush communities, established locally before eruption of Mount Mazama, expanded where soils permitted; sagebrush reached a maximum eastward position > 50 km east of Wildcat Lake before 5400 B.P.
- ☐ Sagebrush gradually gave way to grass between 4400 B.P. and 2400 B.P.
- ☐ The relatively large grass pollen values of the last 9000 years are not reached until into the last 2400 years.

Steppe, eastern Oregon—Steens Mountain, southeastern Oregon, is unusual in lacking a montane coniferous forest zone (McKenzie 1982) and is, therefore, ideal for study of changing steppe vegetation. There, as elsewhere at lower elevations from the northern Great Basin to the Columbia Basin, various amounts of pollen produced by grasses, saltbushes, and sagebrushes are the primary clues to relative abundance of major steppe genera as influenced by climate (fig. 8).

Sites on Steens Mountain also show a long history of treeless vegetation with changing abundance of grass and sagebrush. At Fish Lake, sagebrush steppe followed retreating glaciers to 2300 m by 12,000 B.P., where it now persists. There, late glacial pollen spectra dominated by sagebrush and grass are distinguished from those of the Holocene by larger values of juniper (probably *J. communis* L.) and pine pollen suggesting an early, but short-lived, downwind source.

Cores from Fish and Wildhorse lakes in sagebrush and subalpine steppe, and from Diamond Pond on the sagebrush-shadscale (*Atriplex confertifolia* (Torr. & Frem.) Wats.) desert ecotone, are precisely correlated by six volcanic ashes deposited over the last 6850 radiocarbon years. Fossil pollen exhibits a general three-part division of Holocene vegetational change with differences in the timing of specific events at each site. These differences most probably resulted from effects of temperature and precipitation at various elevations.

Greater abundance of sagebrush pollen in relation to grass pollen indicates relatively low effective moisture at Fish Lake (2250 m) between about 8700 and 4700 B.P. (fig. 11). The mid-Holocene episode of sagebrush pollen abundance began 1500 years earlier than the temperature-controlled upward expansion of sagebrush to Wildhorse Lake (2565 m) about 7200 B.P. Also, it ended at least 1000 years before grass again assumed dominance at Wildhorse Lake (about 3800 B.P.; fig. 11), marking the end of this prolonged but variable period of relatively higher temperatures and reduced snowpack (Mehring 1987).

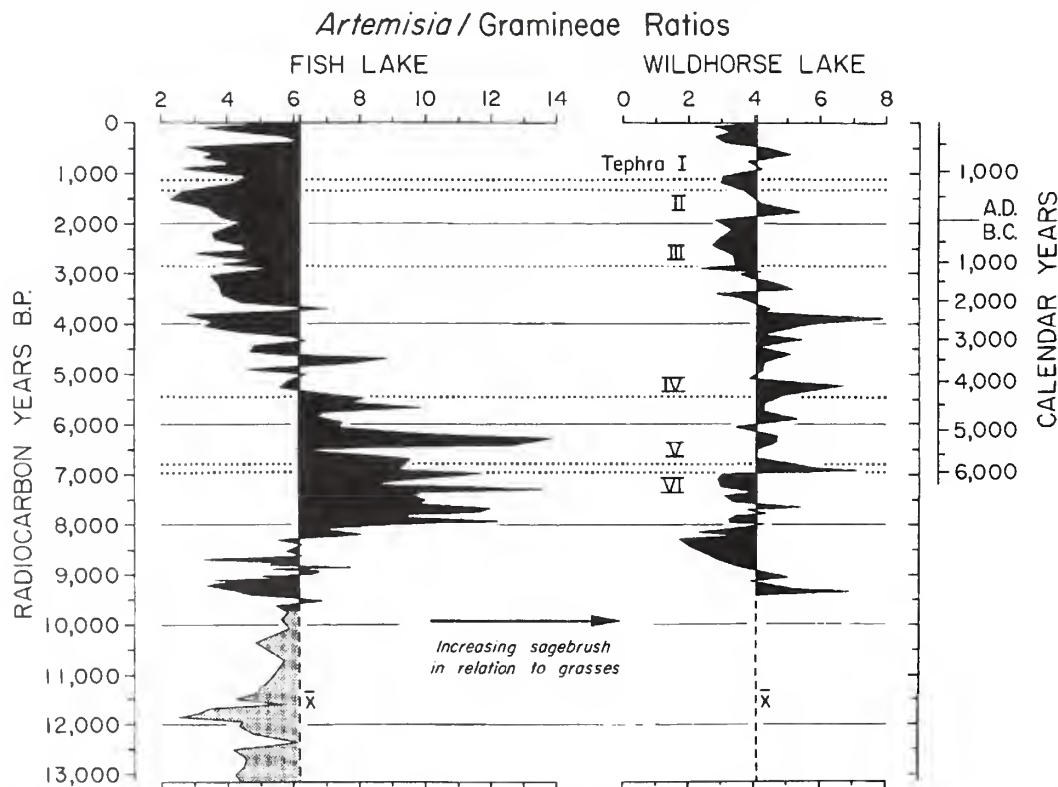


Figure 11. Ratios of sagebrush to grass pollen plotted about their means of the last 9700 and 9300 years B.P. Increase in sagebrush in relation to grass at Fish Lake (2250 m) indicates less effective moisture. The same variations at Wildhorse Lake, 315 m higher, at the current upper elevational limit of sagebrush, suggests up-slope advance of sagebrush because of warmer conditions with fewer snow patches lasting into summer (Mehring 1985).

About the same time (4000 B.P.) at Diamond Pond (Malheur Maar, 1265 m), juniper and grass pollen percentages increased, with declining values of chenopod in relation to sagebrush pollen. Radiocarbon-dated macrofossils of western juniper from woodrat middens in lava tubes confirm that sagebrush and juniper grasslands replaced xeric shadscale vegetation as suggested by the pollen sequence.

In summary, according to the studies reviewed here, cold steppe dominated the eastside during the last glacial period. After 12,000 B.P., wasting glaciers in the north and shrinking pluvial lakes in the south witnessed a brief conifer expansion, but by 10,000 B.P. all sites now in steppe or ponderosa pine, and some in Douglas-fir mixed forest supported grass and sagebrush. In eastern Washington, the forest fringe had apparently retreated 50 to 100 km in the north and east; it would not approach its present lower elevational limits again until after 4400 B.P. In the Steens Mountains region of southeastern Oregon, steppe vegetation persisted at all elevations, but underwent punctuated differences in importance of grass, sagebrush, and juniper, as well as charcoal that reflects the importance of fire. Here, no evidence suggests that western juniper woodlands were present, much less regionally important, until after 4400 B.P.

Juniper woodland—Studies of radiocarbon-dated plant macrofossils from ancient woodrat middens are revealing the responses of desert shrubs and forest trees to late-Quaternary climatic variation to a detail never achieved solely through fossil pollen. In combination, the two complementary methods give greater resolution than either alone (Mehring and Wigand 1990).

Unfortunately, except in the most xeric sites, the eastside's climate is not conducive to preservation of woodrat middens because the hardened dehydrated and crystallized woodrat urine (amberat) that inhibits decay and cements the mass of plant remains is water soluble; even in protected locations, it may dissolve with seasonally high humidity. At lower elevations in dry caves and rockshelters, however, woodrat middens may persist for at least a few hundred years as far north as the dry interior of south central British Columbia. There, Hebda and others (1990) recovered Rocky Mountain juniper (*J. scopulorum* Sarg.) twigs, needles of ponderosa pine and Douglas-fir, and pollen and macrofossils of associated shrubs and herbs from two middens dating to 700 and 1150 B.P. The fossils represent species growing locally today. To the south in the northern Great Basin, woodrat middens 10,000 to 20,000 years old are not unusual; some have been dated to > 30,000 B.P. (Thompson 1990, Wigand and Nowak 1992).

At Diamond Craters (BLM Outstanding Natural Area) in southeastern Oregon, and Lava Beds National Monument in northeastern California, plant remains from woodrat middens in lava tubes and rock shelters give a 5000-year perspective on the spectacular historic success of western juniper, despite programs for its eradication (Mehring and Wigand 1987, 1990). Notions that today's western juniper woodlands are "unnatural" and artificially induced by cattle grazing and fire suppression must be modified in light of recent information from pollen and macrofossils that reveal late-Holocene expanses of juniper most probably exceeding current coverage. The range and abundance of juniper has changed through the late Holocene (figs. 12 and 13). At Diamond Craters, the combination of closely sampled cores from Diamond Pond (Malheur Maar) and woodrat middens in nearby rimrock reveal the reasons for the changing importance of juniper and associated phenomena.

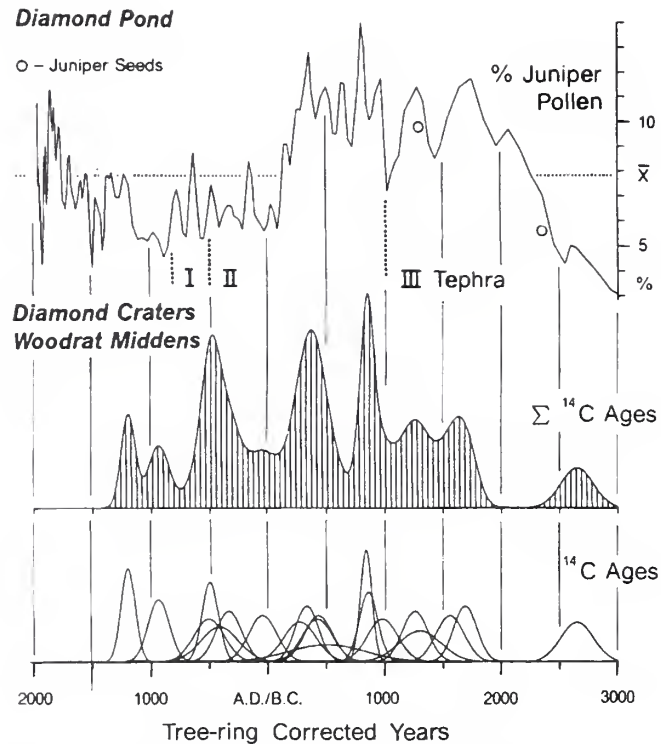


Figure 12. Smoothed juniper pollen percentages and ratios from the Diamond Pond core are plotted about the mean of the average values for each 500-year interval since 5500 B.P. Note correspondence in relative increase in juniper pollen, of grass in relation to sagebrush pollen, and of charcoal in relation to total terrestrial pollen beginning about 4000 B.P. Expansion of juniper woodland, increase in grass, and decline of sagebrush suggested by this diagram are confirmed by macrofossils from woodrat middens (Mehringer and Wigand 1990).

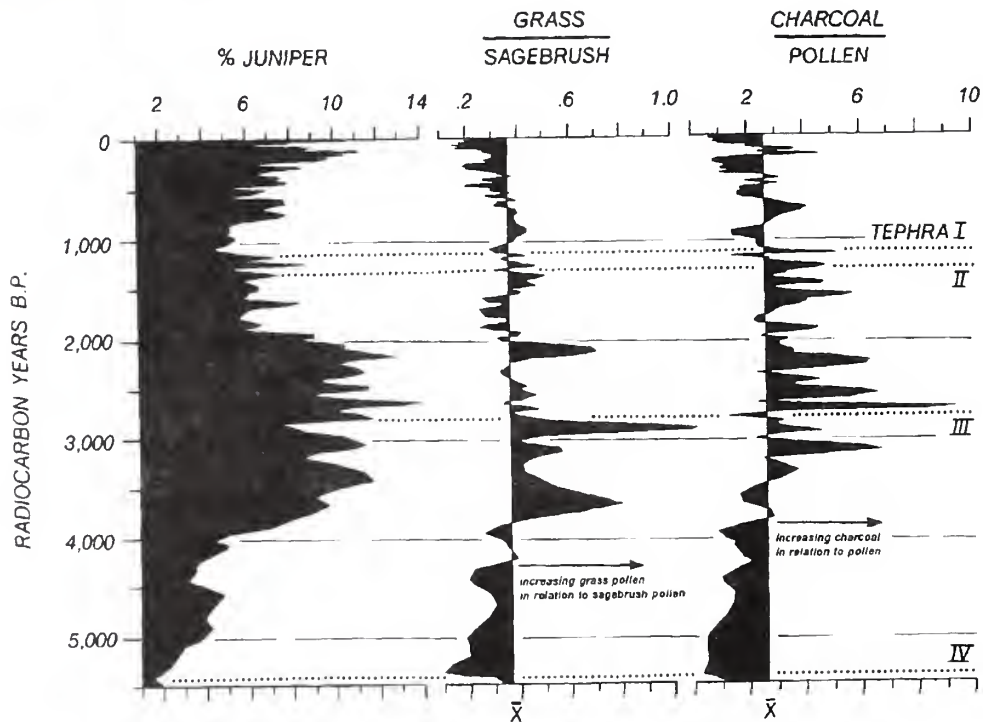


Figure 13. Smoothed percentages of Diamond Pond juniper pollen (fig. 12) and tree-ring-corrected woodrat midden dates, each plotted as a normal distribution with a probability of one; width at the base of each date is three standard deviations. Note that the clusters of midden ages correspond to the larger juniper pollen values from Diamond Pond sediments (Mehringer and Wigand 1990).

Both macrofossils (Wigand 1987) and pollen of pond weeds (*Potamogeton* spp., *Ruppia* spp., *Ceratophyllum* spp.), pond edge species such as cattails and sedges, and differing abundances and types of acid-resistant algae reveal periods of varying water depths and quality, and pond size. Deep, fresher water indicators are associated with relatively more grass in relation to sagebrush pollen and more sagebrush in relation to saltbush pollen. Juniper pollen is most abundant in these same samples. Because the water table is controlled by recharge and evaporation, episodes of deeper water suggest periods of more effective moisture. During these periods juniper expanded its range and sagebrush steppe held more grass.

Confirmation of striking changes in the late-Holocene history of juniper woodlands comes from macrofossils in woodrat middens whose ages correspond to large juniper pollen values between about 3800 and 2200 B.P., with several lesser peaks between 2000 and 700 years ago, and again in the late A.D. 1700s and mid-1900s (fig. 12). These middens hold plant assemblages that record the fluctuating lower elevational border of western juniper onto present, barren basalt flows and into communities now dominated by shadscale desert species. Additionally, at a site in the nearby Catlow Valley, where western juniper is common today, a 6100-year-B.P. woodrat midden dating from a xeric interval lacks juniper macrofossils (Mehring and Wigand 1990). On Steens Mountain, the upper elevational limit of western juniper near Fish Lake has remained unimpeded by competition from other coniferous trees throughout the Holocene. Yet the Fish Lake pollen record does not show western juniper's expansion near its upper elevational limit corresponding to xeric episodes and decline near its lower limit.

According to studies of climate response functions from tree rings, mild winters with ample precipitation and cool springs favor wide annual rings in western juniper (Earle and Fritts 1986, Fritts and Xiangding 1986). The fossil record from Diamond Lake (fig. 12) reveals a relation among the largest juniper pollen percentages and the charcoal to pollen and grass to sagebrush ratios. Algae, plant microfossils, and pollen indicate deeper water during the same period. The woodrat midden fossils and the fossil pollen sequence from Diamond Craters show that juniper's lower elevational limits and abundance changed often over the last 5000 years. On a scale of centuries, juniper increased at times when water tables were higher, grass was most abundant, and fires that favored grass discouraged sagebrush. In the short term, expansion of juniper woodland seems to have been set back by drought and was sometimes ended by catastrophic fires.

Plant macrofossils from woodrat middens from the Pine Creek Drainage of the Clarno Basin, north-central Oregon, also show the history of western juniper in sagebrush steppe. Croft (1989) concluded that the historic expansion of juniper woodlands is not unique and that western juniper, along with bitterbrush (*Purshia tridentata* (Pursh) DC.), was probably more common than now between about 4700 and 4200 B.P. Otherwise, over the last 5000 years, shrubs, such as big sagebrush and shadscale, and grasses varied primarily in relative abundances.

In eastern Oregon, the record of woodlands is short, either because woodland was not important much before 4000 B.P. or because the fossil record is incomplete. Though western juniper abounds there today, the oldest (6100 B.P.) Holocene woodrat midden from Catlow Valley, Oregon, does not contain western juniper. But western juniper is present at Lava Beds National Monument, northeastern California, by 5200 B.P. and represented by a single seed in pond sediments at Diamond Craters, Oregon, at 4800 B.P. (Mehring and Wigand 1987). Just to the south, however, in northwestern Nevada, many more, older, woodrat middens show a long history of shifting distributions of desert scrub, steppe, and woodland.

Study of 96 dated fossil-plant assemblages from 24 woodrat midden localities in northwestern Nevada gave evidence for the 30,000-year presence of Utah juniper (*J. osteosperma* (Torr.) Little) and the arrival of pinyon pine (*Pinus monophylla* Torr. & Frem.) only 1700 to 1000 years ago. Wigand and Nowak (1992) suggest the following sequence of changing vegetation and climate for the region along the western arm of Pluvial Lake Lahontan:

- About 30,000 years ago, during a cold and dry period, Utah juniper woodland had a sagebrush and shadscale understory.

- ❑ After 24,500 B.P., increased moisture encouraged spread of whitebark pine to as low as 1380 m (1300 m below and 10 km from its present nearest locality in the Sierra Nevada). The increased moisture also promoted sagebrush-dominated, moist, open slopes that now support shadscale.
- ❑ By 21,500 B.P., with onset of a cool, dry glacial maximum climate, whitebark pine and Utah juniper gave way to sagebrush-dominated steppe and desert scrub communities.
- ❑ Sagebrush steppe expanded with warmer and wetter conditions of the late glacial period.
- ❑ After 10,000 B.P., much warmer and drier conditions favored shadscale communities at the expense of sagebrush steppe and juniper woodlands.
- ❑ After 4000 B.P., under cooler and more mesic conditions, sagebrush steppe and juniper woodlands regained importance.
- ❑ Ponderosa pine arrived in the region only 2000 years ago.
- ❑ Macrofossils of pinyon pine finally appeared in woodrat middens between 1700 and 1000 B.P.

Forests—Pollen records from present forests east of the Cascades consistently reveal that the first invading conifers flourished on what had been glacier or lake-covered terrain, flood tracts, or frozen ground supporting cold steppe during the last full-glacial episode. In some places, these conifers persisted; in others, they gave way to grasses and steppe shrubs that remain to the present day or, after a few thousand years and changing climate, were in turn overrun by forests that burned repeatedly but held their ground.

The fossil pollen localities most important in deciphering forest history east of the Cascades are reviewed below. These few records come pitifully short of detailing forest history. They do, however, reveal the broad sweep of changing forest vegetation in response to climate. They also expose specific topical and geographical areas of near total ignorance. For example, despite a few pollen diagrams from the region, the full-glacial fate and Holocene history of northern Idaho's moist maritime hemlock and cedar forests—unrecorded in fossil pollen sequences before 2500 B.P.—remain a puzzle. Likewise, late-Quaternary vegetation of the Blue Mountain region of northeast Oregon and adjacent Washington (including the Wallowa, Ochoco, Strawberry-Aldrich, Greenhorn, and Elkhorn ranges) remains unknown for lack of study.

A combination of related factors—including fire suppression, some logging practices, and insect infestations—have left the forests of the Blue Mountains teetering on the edge of an ecological disaster. If appropriate fossil pollen and plant macrofossil data were available, these conditions could be evaluated in terms of natural, long-term disturbances. Even without this urgency, any study of eastside forest history should, perhaps, emphasize forests of the Blue Mountains because of their extent and diversity (Johnson and Clausnitzer 1992). The only two published pollen records from this entire region come from a few exploratory samples collected by Henry P. Hansen (1943) from Anthony Lakes, which offer little information in a modern context, and, from the Silves Valley (Craddock Meadow, 1630 m), which span most of the Holocene. Only 23 samples were analyzed, and pollen was poorly preserved. Ponderosa pine, western juniper, and big sagebrush (*A. tridentata* Nutt.) interfinger in Craddock Meadows area today, yet sagebrush was the dominant pollen from about 9000 B.P. until 2000 years or so after the Mazama ashfall. Only then did pine pollen values to 60 percent suggest presence of ponderosa pine. Two nearby woodrat middens, dating to 1280 (juniper twigs) and 300 B.P., held species now present at the site (Reid and others 1989).

Cursory examination of cores from two other sites indicate the potential for detailing eastside forest history for northeastern Oregon. Cores from Twin Lakes in the Wallowa Mountains and Lost Lake near Dale, Oregon, show well-preserved pollen and macrofossils in post-Mazama sediments (Mehring unpub.). For instance, Lost Lake, in mixed Douglas-fir, grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) forest, holds abundant charred Douglas-fir cones and needles in redeposited Mazama tephra. Pollen samples from 3000-year-old sediment show mountain hemlock pollen values indicating a nearby

source at that time, whereas younger tephra blankets a layer of western larch needles (*Larix occidentalis* Nutt.). Larch grows nearby today, but the nearest mountain hemlock are about 110 km to the northeast in the Wallowa Mountains (Johnson and Simon 1987).

In the north, Mack and others (1978a, 1978b, 1978c, 1978d; 1979; 1983) studied several sites, from the San Poil to Priest River valleys of northeastern Washington, northern Idaho, and into adjacent Montana (fig. 14). These sites, along with Williams Lake Fen and Goose Lake, show the local sequence of forest history and also suggest regional trends. Some of these trends could have been anticipated from the discussion of the history of eastern Washington's steppe. They include:

- ❑ Sediments dating to at least 12,000 B.P. show an initial treeless episode dominated by pollen of sagebrush and grass. Spruce, fir, and lodgepole and other pines arrived before the fall of Glacier Peak tephra (11,250 B.P.).
- ❑ Mixed conifers, sometimes with birch (*Betula* spp.), dominate for the next 1000 years or so.
- ❑ By 10,000 B.P., grass or sagebrush began to assume dominance at lower elevations. To the east in northern Idaho and adjacent Montana, larch and Douglas-fir, along with diploxylon pine pollen (lodgepole or ponderosa), and small but persistent percentages of grass and sagebrush pollen indicate predominance of widespread steppe and dry interior forests.
- ❑ By 4000 B.P., as sagebrush steppe retreated toward eastern Washington's arid central core, the forest fringe (ponderosa and lodgepole pine, and larch or Douglas-fir) had begun to advance west and south, and perhaps downslope from the Cascades as well. Spruce and fir pollen increased at sites within the former forested areas.
- ❑ Between 2500 and 1000 B.P., fossil counterparts of modern forest were apparent at most sites, and eastern Washington's grasslands finally began to achieve their historic importance.

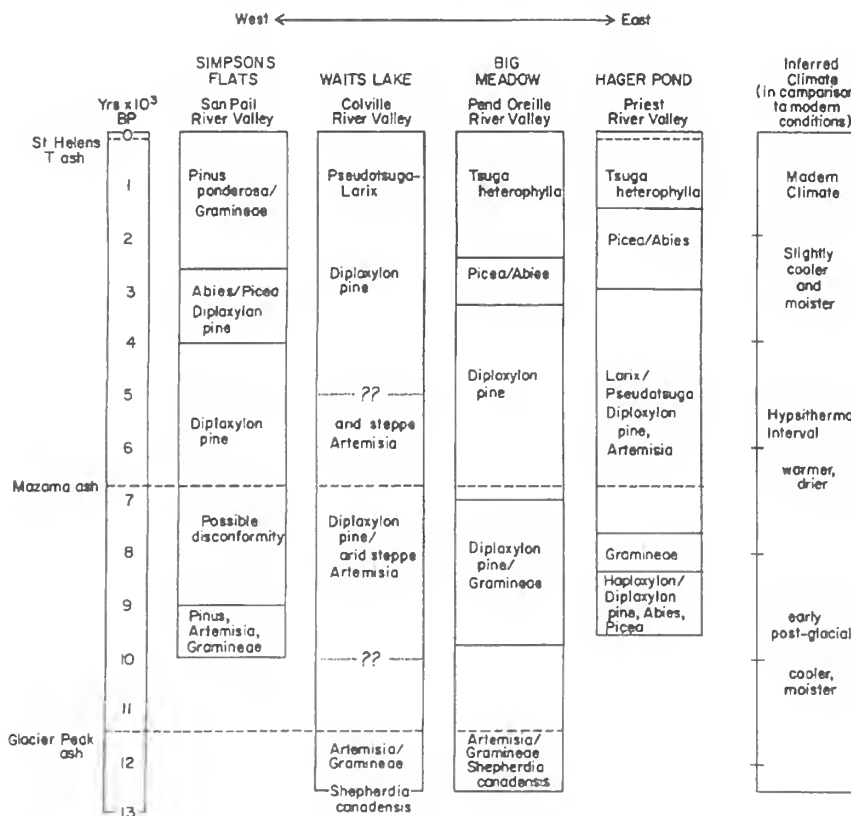


Figure 14. Summary of vegetation dominants and inferred climatic changes for sites in northeastern Washington and northern Idaho since recession of the last ice sheet (from Mack and others 1978d).

To the east, at elevations above 1900 m in the Bitterroot Mountains (Lost Trail Pass, Montana: Mehringer and others 1977a, b) and smaller ranges (Sheep Mountain Bog, Montana: Hemphill 1983, Mehringer 1985, Mehringer and others 1984), coniferous forests dominated throughout the Holocene. Timing and direction of changing vegetation suggest that forest species were reacting similarly to the climatic patterns that influenced the vegetation of eastern Washington.

Sheep Mountain Bog (1920 m), 18 km northeast of Missoula, Montana, lies at the upper limit of ponderosa pine and larch on south-facing slopes. Mixed forests with subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and Engelmann spruce surround the bog. According to fossil conifer needles and cones (Mehringer, unpub.), Douglas-fir has grown near this site since at least 10,000 B.P. Its largest pollen frequencies occur between 9700 and 4000 B.P., along with pollen and macrofossils of lodgepole pine and pollen of ninebark (*Physocarpus* sp.); all of which suggest a dry mid-Holocene forest. Haploxylon and diploxylon pine pollens are represented by macrofossils of whitebark and lodgepole pines. Haploxylon pine pollen (whitebark) is most abundant, along with macrofossils and pollen of spruce and fir, only between 11,000 and 10,000 B.P. This abundance may reflect the short-lived cooling of the Younger Dryas episode described for Williams Lake Fen. The importance of Douglas-fir diminished relative to spruce and fir pollen, which showed marked increases after 4000 B.P.

Before the fall of Glacier Peak ash, subalpine conifers began to fill higher elevations of the Bitterroot Range near Lost Trail Pass Bog (2152 m), where they grow today. Then, before the fall of Mazama ash (about 6850 B.P.), grass and sagebrush pollen percentages, along with pollen of the warmth-requiring Douglas-fir and lodgepole pine replaced the more cold-tolerant whitebark pine. Upslope migration and persistence of Douglas-fir marks a period of undoubted warming, yet an unbroken sedimentary record indicates that the small pond at Lost Trail Pass did not go dry.

About 4000 B.P., Douglas-fir lost dominance to whitebark and lodgepole pines, perhaps for the first time in 5000 years, and retreated to warmer downslope positions. Since that time and especially after 1750 B.P., the vegetation was apparently similar to the present, with at least one unusually cool (and wet?) climatic episode around 3600 B.P. This later event is perhaps the same one noted elsewhere (for example, at Blue Lake near Lewiston, Idaho; Carp and Wildcat Lakes, Washington).

Blue Lake, Idaho (1035 m), is now surrounded by Douglas-fir and ponderosa pine; varying abundances of the pollen and macrofossils of these two trees suggest important variations in effective moisture over the past 4300 years. According to Smith (1983), a relatively warm, moist interval, dominated by Douglas-fir, from 4300 to 4000 B.P. preceded a cooler period from 4000 to 3000 B.P., with mixed Douglas-fir, lodgepole, and ponderosa pine. Then, conifer pollen decreased from 3000 to 1700 B.P., and dry, open, ponderosa pine parkland persisted until 1000 B.P., when vegetation similar to present day's emerged.

Volcanic Ash (Tephra) and Charcoal

Late-Quaternary volcanic eruptions, wild fires, and fires set by the prehistoric inhabitants no doubt influenced vegetation history. Where influences were extreme, the ecological effects of volcanic activity are obvious. But immediate effects and the long-term consequences of any prehistoric catastrophe—even one as severe as the eruption of Mount Mazama (Crater Lake, Oregon)—are not always discernible. No one can say exactly how most vegetation of the northwestern United States would be different if Mount Mazama, Mount St. Helens, or Glacier Peak had been inactive in the last 20,000 years, nor in what ways the magnitude and timing of their eruptions determined or altered the course of Holocene vegetational "development." Certainly, pumice soils of east-central Oregon favor lodgepole pine. For the Yellowstone National Park region, Whitlock (in press) also ascribes differing vegetational histories to volcanic soils. There, over the last 5000 years, mixed forests of pine, spruce, and fir developed on andesitic and non-volcanic soils, and closed lodgepole pine forests persisted on rhyolitic soils.

Effects of an ashfall on terrestrial or aquatic ecosystems depend on thickness of primary and secondary tephra, season and duration of the ashfall, and time separating recurrent eruptions. Therefore, estimates of the depositional chronology of ashfalls is essential to evaluating their influences (Blinman and others 1979, Mehringer and others 1977b). Sagebrush pollen from Mazama tephra at Lost Trail Pass, Montana (fig. 2), suggested an autumn ashfall. A graded bed of clean tephra with little pollen and lack of seasonal indicators implies that Glacier Peak tephra fell at Sheep Mountain Bog, Montana, when the lake was ice free and probably in late summer (Mehringer and others 1984).

Varying charcoal accumulation rates, pollen-to-charcoal ratios, and washed-in charcoal layers may reveal the history of fire in forest and steppe (fig. 13; MacDonald and others 1991). The observation that charcoal was unusually abundant over the past 2000 years or so near Lost Trail Pass, Bitterroot Mountains, Montana, led to three studies of late Holocene relations between reconstructed vegetation, charcoal layers, and charcoal and pollen abundance in lake sediments. Three widely separated sites showed the same broad chronological patterns of changing charcoal abundance over at least the past 7000 years or more (Mehringer 1985, table 3). All sites showed the largest charcoal-to-pollen ratios during the last 1000 years. Perhaps this superabundance of charcoal is related to increasing populations of Indians, who used fire as a management tool (Barrett and Arno 1982, Gruell 1985). Leiberg (1900, p. 314-316) estimated that Indians burned 2,270,000 acres (9183 km²) during the last 200 years before their populations plummeted as a result of small pox, measles, and conflicts.

At Blue Lake, near Lewiston, Idaho, severe fires, resulting in distinctive bands of washed-in charcoal, burned through Douglas-fir forests about once every hundred years between 4300 and 4000 B.P. Only two severe fires in mixed conifer forests left charcoal layers between 4000 and 3100 B.P., but such fires were nearly twice as common between 3100 and 1700 B.P. From 1700 to 1000 B.P., severe fires averaged only one in 175 years. Light surface fires, leaving no charcoal layers in the lake sediments but producing abundant microscopic charcoal, characterized the last 700 years (Smith 1983).

Fire frequency, as evidenced by the charcoal-to-pollen ratio at Sheep Mountain Bog, Montana, declined gradually between 7000 and 2000 B.P. and then increased to produce a superabundance of microscopic charcoal during the past 1000 years. These peaks of charcoal in bog sediments proved comparable with tree fire-scar studies and historic records (Hemphill 1983). A remarkable record of early and middle Holocene fires comes from deposits of Sheep Mountain Bog.

The sedimentary sequence at Sheep Mountain Bog began about 12,500 B.P., with till left by the wasting glacier that had carved the > 12-m-deep depression. From that time, the depression held a lake that accumulated primary and redeposited Glacier Peak and Mazama tephra, and distinct layers of charcoal. These layers were graded beds and usually formed couplets. Sand, coarse silt, and charcoal made up the lower black layer of each couplet, and the upper layer consisted of gray wood ash and clayey silt. In all, 167 layers (most of them couplets) were measured with a dissecting microscope (fig. 15). Between 10,600 and 4000 B.P., erosion after fire accounted for at least 23.5 percent of sediments deposited in the basin.

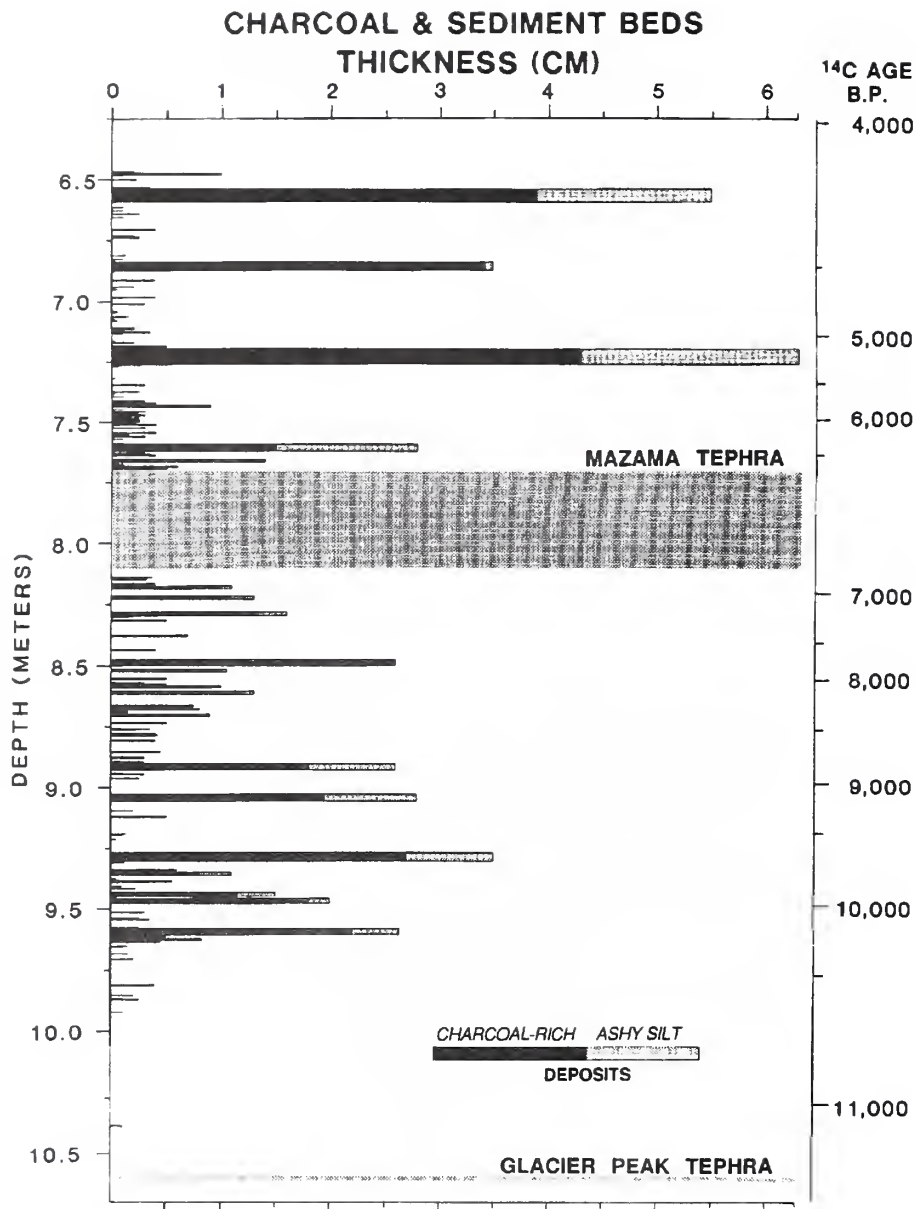


Figure 15. Widths of black charcoal-rich sands and silt layers overlain by gray, ashy silt and clay layers containing fine charcoal and ash. These couplets, and occasional single charcoal-rich layers, resulted from wash-in after fire and, therefore, afford a 6000-year record of the number and intensity of fires in the basin of Sheep Mountain Bog (Mehringer, unpub).

The charcoal, ash, and sediment layers resulted from erosion into the lake after fire and, therefore, afford a record of fires in the basin. The thickest layers most likely result from severe erosion after high-intensity, duff-destroying fires, and the thinner layers represent low-intensity fires. By 4000 B.P., a filtering fringe of vegetation surrounded the gradually filling pond, and slopewash deposits no longer reached the coring site. Distribution of the measured layers show no single "natural" fire regime in the 6400 years represented by charcoal layers; three patterns are evident:

- ☐ Many small fires (around 6000 B.P.);
- ☐ Small fires with occasional large fires (around 8000 B.P.); and
- ☐ Few small fires followed by potential stand-replacing fires (around 5400-4200 B.P.).

The first charcoal layer was deposited about 11,150 B.P., while lodgepole pine dominated scattered woodlands. Four narrow (0.52.5 mm) laminae form the first cluster of charcoal layers about 10,600 B.P. At this time, the site supported scattered whitebark pine with spruce and fir; sagebrush occupied openings.

Between 10,200 and 9600 B.P., the number and intensity of fires suggest a different climatic regime. By the end of this period, lodgepole pine and Douglas-fir largely replaced whitebark pine, spruce, and fir. This first period of abundant charcoal at Sheep Mountain Bog is also the period of demise of conifer woodlands in east-central Washington and the largest pre-Mazama charcoal values at Williams Lake Fen (fig. 5). The number of fires increased around 8000 B.P., when pollen frequencies show the largest values of Douglas-fir and smaller values of pine pollen, primarily lodgepole pine.

From 5400 to 4200 B.P., many, very small fires burned, and, judging by thickness of the charcoal layers, the three largest fires burned. At Sheep Mountain Bog, this period saw increasing percentages of pine, spruce, and fir pollen and decreasing Douglas-fir pollen. Perhaps fewer low-intensity fires, such as those that marked the preceding 1000 years; or perhaps more ground cover supported occasional light fires, but inhibited slope wash. In either case, during this 1200-year period, the basin of Sheep Mountain Bog apparently experienced three conflagrations unlike fires of the earlier Holocene and any of the last 1000 years or more (Hemphill 1983).

THE PAST AS KEY TO THE PRESENT—AND FUTURE

In a human life span or two, eastside communities may seem predictable. On this scale, vegetation history can be explained by observed succession in the enduring harmony of climax communities. The idealized stable cycles, always returning to the natural state, are unfortunately just a few frames in a continuous movie (Graham 1988). They are illusions of forest and steppe primeval—the pristine vegetation of the imagination.

Effects of cows, plows, and alien weeds have sped up the movie, but still leave room for short-term predictability, with no necessary appreciation for the longer view. The specter of sudden global warming and fates of ecosystems (Franklin and others 1991) are, however, another matter. Short-term observations provide few analogs for the magnitude and extent of past and potential vegetation change.

Two principles emerge from paleo-vegetation studies here and elsewhere in North America: change is continual and change is unpredictable. Although change may be imperceptible in the center of mixed montane forest or steppe, sensitive sites on the fringes often show that plants, even long-lived trees, respond rapidly to disturbance. For example, buried needles, cones, and whole logs of spruce and alpine fir above tree line in the Canadian Rockies show upslope advances to > 110 m above present tree line between 9000 and 5000 B.P. and again near 1000 B.P. (Luckman 1990). These warm (+0.5-1.5° C), temperature-controlled responses at the tree line affect only a small area of vegetation. In eastern Washington and Oregon, even slight changes at the lower forest border have a great influence on total areas of vegetation types.

The eastside's steppe-conifer ecotone has been in flux over the past 12,000 years. In eastern Oregon, historical and past successes of western juniper are impressive because a small increase in effective moisture and downward displacement of western juniper brings wide expanses of woodlands. The same is true for the steppe-ponderosa pine border in eastern Washington (fig. 10). Change is perpetuated not only by plant responses to climate, but by disturbances that accompany climatic change—and fire is the most obvious of these disturbances.

At Williams Lake Fen, falling water tables and fire brought an end to the scabland's late-glacial woodlands and the beginning of expansive steppe (figs. 5, 7, 10). The record of pollen and charcoal from Diamond Pond, Oregon, shows a different sequence, but a similar effect—trees were lost to fire. There, in short drought periods during generally favorable times (2000-4000 B.P.), fuel in grasses carried fires that set back

juniper woodlands when they had become dense enough to carry some fires themselves. If vegetation changes lag behind climatic changes (Franklin and others 1991), then—in the long view—vegetation is often out of equilibrium with climate and subject to rapid change through disturbances such as disease and fire.

The second principle, unpredictability, is best illustrated by unfamiliar late-glacial and Holocene assemblages of both plants and animals. These assemblages suggest that individuals, rather than communities or vegetation zones, react to climatic change and that fossil assemblages and modern communities are loosely organized collections of individually distributed species. With disturbances, species may be redistributed along different environmental gradients and at different rates, and may reassemble in unpredictable ways (Graham and Grimm 1990). In short, present communities are not necessarily good guides to the past, nor to the future. In Quaternary vegetation, surprises are the rule (Franklin and others 1991).

By studying today's communities, without reference to the fossil record, we could not have known that the eastside's familiar broad distributions of woodland and steppe did not take shape until after 4000 B.P., that northern Idaho's hemlock and cedar forests were even younger, or that a few centuries ago and many times during the last 4000 years, juniper woodland's expanse exceeded that of its historic spread. The remarkably rapid demise of the scabland's, late-glacial woodlands shows the process and pace of total replacement, and the potential magnitude of future vegetation change with rapid global warming of 4 to 5°C (Overpeck and others 1991).

Two primary areas need considerable study before eastside forest history can be understood. The first is the historical process by which moist, maritime forest communities of northern Idaho and adjacent Washington and Montana became so successful in apparently less than 3000 years (Mack and others 1978a). When did hemlock, cedar, and associates typifying present habitat types arrive (Cooper and others 1991)? When did they become abundant, and what role did stand-replacing fires and succession have in their initial success and regeneration (Moeur 1992)? These questions are just a few that might be answered by macrofossils and pollen from the lakes and bogs of this region.

The second, and perhaps most important, area is the Blue Mountains of northeastern Oregon and adjacent Washington. Here, near total ignorance about vegetation history leaves room for imagination. With the vision of Janus and fossil plant records, scientists may unravel the past and thereby achieve a wise view of future eastside ecosystems.

DESCRIPTION OF EASTSIDE VEGETATION

The vegetation on the landscapes of the intermountain Pacific Northwest (east of the Cascade Range and west of the Rocky Mountains in Washington and Oregon) is influenced by climate, landforms, soils, and relief. Climates of either maritime or continental derivation provide the temperature and moisture required by the individual plant species that make up the communities across the landscape. The landscape is highly varied on the east side of the Cascade Range. Therefore, the variation in kinds of plant communities found across the inland Pacific Northwest is also highly varied.

Climax plant communities on the eastside can be divided into forests, grasslands, shrublands, and wetlands. Our description of eastside vegetation follows the classification work by taxonomic plant ecologists over the past 25 years (Daubenmire and Daubenmire 1968, Daubenmire 1970, Hall 1973, Hopkins 1979a, 1979b, Williams and Lillybridge 1983, Clausnitzer and Zamora 1987; Johnson and Simon 1987, Kovalchik 1987, Volland 1988, Williams and others 1990; Williams and Smith 1991; Johnson and Clausnitzer 1992).

Forests

Subalpine fir zone—The highest mountain elevations contain the harshest temperature extremes for forest vegetation. Subalpine fir is capable of persisting in the cold, wet or cold, dry environments at high elevations. Desiccating winds also provide a limiting factor to species and type of community. Three primary series where coniferous trees form the climax dominant plant layer are the subalpine fir, mountain hemlock, and whitebark pine series:

- ❑ Subalpine fir series—All forest stands are dominated at climax by subalpine fir or Engelmann spruce. Spruce is longer lived and is co-climax in many late seral stands, especially on moist sites and cold-air pockets. Subalpine fir is dominant when sites are too cold for other shade-tolerant species to reproduce. Lodgepole pine is the principal seral fire species associated when stand-replacing fires have occurred. Douglas-fir and western larch are important seral species on warmer, drier sites—especially on southerly slopes at higher elevations or at the lower slope elevations adjacent to the grand fir zone.

The following plants are important members of climax communities with subalpine fir, spruce, or both in the eastside forests: twisted stalk (*Streptopus amplexifolius* (L.) DC.), false bugbane (*Trautvetteria caroliniensis* (Walt.) Vail), queenscup beadlily (*Clintonia uniflora* (Schult.) Kunth.), bunchberry (*Cornus canadensis* L.), twinflower (*Linnaea borealis* L.), false huckleberry (*Menziesia ferruginea* Smith), Cascades rhododendron (*Rhododendron albiflorum* Hook.), grouse huckleberry (*Vaccinium scoparium* Leiberger), big huckleberry (*V. membranaceum* Dougl.), dwarf blueberry (*V. caespitosum* Michx.), delicious blueberry (*V. deliciosum* Piper), red mountainheath (*Phyllodoce empetriiformis* (Sw.) D. Don), bearberry (*Arctostaphylos* spp.), Hitchcock's woodrush (*Luzula hitchcockii* Hamet-Ahti), pinegrass (*Calamagrostis rubescens* Buckl.), elk sedge (*Carex geyeri* Boott), skunkleaved polemonium (*Polemonium pulcherrimum* Hook.), and beargrass (*Xerophyllum tenax* (Pursh) Nutt.).

- ❑ Mountain hemlock series—Mountain hemlock communities are limited to northerly aspects below ridgetops where deep snowpacks and cold temperatures persist throughout the year. Two huckleberries, big huckleberry and grouse huckleberry, form climax communities with mountain hemlock in northeastern Oregon. Hitchcock's woodrush occurs in climax communities with mountain hemlock in northeastern Washington.
- ❑ Whitebark pine series—High winds, severe desiccation, ice pruning, and snowfall create open stands, clumped stands, and krummholz communities at the upper limits of tree growth. Climax communities are dominated by fleecflower (*Polygonum phytolaccaefolium* Meisn.), Drummond's rush (*Juncus drummondii* E. Meyer), and skunkleaved polemonium.

Grand fir zone—The most extensive environmental zone in the eastside is characterized by cool, moist or dry to warm, moist growing conditions where grand fir is the climax dominant tree species. The relation of moisture to temperature, coupled with ash or ash-influenced soils, provides for ideal coniferous tree growth and productivity. The grand fir series is normally bounded by subalpine fir at upper elevations and Douglas-fir climax vegetation on lower slopes. The principal seral tree species are lodgepole pine, western larch, Douglas-fir, and ponderosa pine.

Cool, moist environments provide grand fir climax communities with false bugbane, queenscup beadlily, Pacific yew (*Taxus brevifolia* Nutt.), Rocky Mountain maple (*Acer glabrum* Torr.), twinflower, and big huckleberry. Cool, dry environments provide grand fir climax communities with grouse huckleberry, dwarf blueberry, ninebark (*Physocarpus malvaceus* (Greene) Kuntze), Columbia brome (*Bromus vulgaris* (Hook.) Shear), pinegrass, and elk sedge. The warm, moist maritime climate provides climax communities of grand fir with oakfern (*Gymnocarpium dryopteris* (L.) Newm.), sword fern (*Polystichum munitum* (Kaulf.) Presl.), and ginger (*Asarum caudatum* Lindl.).

Douglas-fir zone—Douglas-fir is climax on sites that are more mesic than climax ponderosa pine sites; sites too dry for subalpine fir or grand fir. Tree species that may be seral to Douglas-fir are ponderosa pine, western larch, and lodgepole pine. Midsummer drought is a limiting factor to establishment by some shrub and herbaceous species. Cool, moist environments provide Douglas-fir climax communities containing Rocky Mountain maple, ninebark, big huckleberry, dwarf blueberry, mountain snowberry (*Symphoricarpos oreophilus* Gray) and common snowberry (*S. albus* (L.) Blake). Warm, dry environments

provide Douglas-fir climax communities containing birchleaf spiraea (*Spiraea betulifolia* Pall.), oceanspray (*Holodiscus discolor* (Pursh) Maxim.), bearberry, western fescue (*Festuca occidentalis* Hook.), pinegrass, and elk sedge.

Ponderosa pine zone—Ponderosa pine is widely distributed throughout eastern Oregon and Washington but is climax on the warmest, driest forest sites. It is a major seral species in Douglas-fir and grand fir series communities but forms a climax community near the limits of tree growth imposed by drought. Of the tree-dominated vegetation on the east side, only western juniper woodlands occur on warmer, drier sites than climax ponderosa pine communities. Ponderosa pine climax communities occur on coarse, sandy soils and where fissures in the underlying bedrock permit the tree to tap deep moisture sources. Other trees often associated with climax ponderosa pine communities are western juniper, quaking aspen (*Populus tremuloides* Michx.), lodgepole pine, and Oregon white oak (*Quercus garryana* Dougl. ex Hook.).

Principal climax communities are formed with the following shrubs: mountain-mahogany (*Cercocarpus ledifolius* Nutt.), bitter-brush, mountain snowberry, common snowberry, and mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana*). Oregon white oak is associated with ponderosa pine in north-central Oregon and south-central Washington (Topik and others 1988). Principal climax communities are formed with the following herbaceous species in eastern Oregon and Washington: pinegrass, elk sedge, Wheeler's bluegrass (*Poa nervosa* var. *wheeleri* (Vasey) Hitchc.), Idaho fescue (*Festuca idahoensis* Elmer), and bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith).

Western juniper zone—Toward the Great Basin, with its cold desert and continental climate, ponderosa pine is incapable of survival. The western juniper occupies an environmental zone between the pine and the shrub-steppe of the Great Basin. Western juniper forms climax communities with mountain-mahogany, bitter-brush, big sagebrush, elk sedge, and the two principal bunchgrasses—bluebunch wheatgrass and Idaho fescue.

Shrublands

The shrublands of the eastside can be separated into two kinds—climax and seral. Shrublands may be seral in forest successional pathways. Climax shrublands are communities where a shrub species is the dominant life form on sites where conditions will not support a forest community. The climax shrub communities of the eastside provide diversity to the landscape as part of a vegetation mosaic. Shrublands are often found intermediate between forests and grasslands, and between scablands and wetlands. Climax shrublands can be grouped artificially as follows: mesic shrublands, where ninebark and common snowberry occur with rhizomatous sedges and grasses, and sagebrush shrublands where the most mesic species (mountain big sagebrush) forms communities with mountain snowberry, elk sedge, and Idaho fescue; where low sagebrush (*Artemisia arbuscula* Nutt.) forms communities with Idaho fescue and Sandberg's bluegrass (*Poa sandbergii* Vasey); and where stiff sagebrush (*A. rigida* (Nutt.) Gray) forms a community with Sandberg's bluegrass.

The driest and hottest habitats with shrubland communities are found in the deep canyons of the eastside. Here, smooth sumac (*Rhus glabra* L.), netleaf hackberry (*Celtis reticulata* Torr.), and green-bush (*Glossopetalon nevadensis* Gray) form communities with bluebunch wheatgrass. Other common shrublands that form climax communities are bitter-brush and mountain-mahogany.

Grasslands

The climax grasslands in eastside Oregon and Washington are dominated by bunchgrasses on sites that are incapable of supporting forest or shrubland communities. They constitute a fairly high percentage of the landscape in canyonlands and on lower montane ridges. The grasslands can be separated into five groupings as follows:

Subalpine grasslands—Green fescue (*Festuca viridula* Vasey) occurs principally in the Willowa Mountains of northeastern Oregon at elevations above 7000 feet. It occurs with sedges, rushes, and forbs. Idaho

fescue and elk sedge are found on subalpine summits of the Blue Mountains in communities with various subalpine forbs. Disturbance from overgrazing has resulted in subalpine forbfields and grasslands at higher elevations, where the two fescues have been replaced by needlegrasses (*Stipa* spp.), lupines (*Lupinus* spp.), and phloxes (*Phlox* spp.).

Mesic grasslands—Idaho fescue forms climax communities at upper canyon elevations, on favorable aspects at lower elevations, and on deeper soils of the ridges where moisture is retained longer into the summer drought period. Principal plants associated with fescue in these communities are prairie junegrass (*Koeleria cristata* Pers.), bluebunch wheatgrass, and Hood's sedge (*Carex hoodii* Boott).

Xeric grasslands—Bluebunch wheatgrass dominates in these drier, warmer habitats. Many different climax communities occur in the eastside grasslands, often associated with Sandberg's bluegrass.

Scablands

Scablands occur where soil depth is less than 10 inches and an impervious bedrock limits establishment of deeper rooted plants. Occupying these sites is a vegetation unique to the harsh environmental extremes caused by freezing and thawing, and saturated soils in the spring followed by hot, desiccated soils in the summer. Onespike oatgrass (*Danthonia unispicata* (L.) Beauv.) and Sandberg's bluegrass are climax on these scablands. The deep canyons provide specialized habitats for grasslands occupied by sand dropseed (*Sporobolus cryptandrus* (Torr.) Gray), red threeawn (*Aristida longiseta* Steud.), and giant wild rye (*Elymus cinereus* Scribn. & Merr.).

DISTURBANCE AS A NATURAL EVENT IN EASTSIDE ECOSYSTEMS

The vegetation of eastside Washington and Oregon has a long history of natural disturbance. Unlike other ecosystems where stability is measured in centuries, eastside ecosystems are considered stable when the period between modifying events is decades. Eastside vegetation, as a reflection of climate and topography, is comprised of plants with reproductive mechanisms capable of withstanding relatively frequent, severe disturbances.

The principal disturbance processes have provided vegetation opportunities for adaptation to periodic disturbances of varying severity. The primary disturbance processes affecting plant communities of the eastside are fire, grazing and browsing by ungulates, insect outbreaks and disease epidemics, windthrow, flooding, and erosion (mass wasting).

The Disturbance Paradigm of Forest Ecosystem Development

The ubiquity of natural disturbances became better appreciated as modern communication and transportation allowed the human population to see the size and extent of natural disturbances. The hurricane of New England that affected 600,000 acres of forest was not unlike similar hurricanes of 1815. Hurricanes Hugo and Camille were also not unusual, because similar ones occurred in 1972, 1969, 1965, and 1955 (Oliver and Larson 1990). The Yellowstone fires of 1988, which burned 1,408,000 acres, were similar to the Entiat fire of north-central Washington, which destroyed over 200,000 acres of forests in 1970, and to the fires in the Colville, Washington area of the 1920s, which also destroyed hundreds of thousands of acres.

The importance of disturbances has become more appreciated now that biologists recognize that forests do not immediately return through a single pathway of forest change (succession) to a single, stable condition (climax) after a disturbance. Instead, both natural and human disturbances have long-term influences on the appearance and composition of forests.

Forests consist of tree species not coevolved to grow with each other in mutualistic support. In fact, many species currently found together have not been together for many tree generations. The short life span (and often shorter memory) of people relative to tree life spans (hundreds of years) gives the mistaken impression of stability and constancy of the forests.

Fire as a Rejuvenating Event

Throughout the presettlement period, fire was an integral part of the maintenance and function for the majority of eastside ecosystems. The seasonal cycling of fire through the landscape was as regular as the incidence of late summer lightning occurrence in the canyonlands and mountains of this region. The periodicity of fire in certain plant communities has been determined by investigators for many forested plant associations (see review by Agee 1993) and has been estimated for several key grassland plant associations (Volland and Dell 1981). Depending on the composition of the community, its structural configuration, and the buildup of dead plant biomass, fire resulted in burns of various intensities and extension across the landscape. The shorter the return interval between fire events, the less dramatic would be the result of the fire on plant composition. With infrequent return intervals, stands tended to burn hotter and be replaced by a vegetation often different in composition, structure, and age from what it replaced.

The variation of landform and climatic patterns have combined to provide a rich mosaic of plant communities across the eastside. As annual lightning storms would play across this landscape, a patchwork quilt of various-sized patches, textures, and kinds of vegetation would result. This mosaic would be as resilient and dynamic as the annual play of storm-induced fire. The probability of fire in any given place would be a function of chance, the position on the landscape relative to storm-building geographic features, and the vulnerability of the plant community to fire.

The period since settlement and subsequent growth of industry by Euro-Americans has seen the curtailment of fire as a periodic modifying event in the vast majority of eastside plant communities. Over the past 130 years—and even more dramatically in the past 60 years—vegetation has changed from stands dominated by seral fire-adapted species to stands and communities where fire-susceptible species predominate and form “unhealthy” stand configurations. The classic example has been the widespread disappearance of open, parklike stands of ponderosa pine with the ingrowth of grand fir as a result of fire exclusion. Likewise, in grand fir plant associations where ponderosa pine is not seral to grand fir, fire has not been allowed to perform its natural role of stand-replacement burning. The poor vigor of these stands has contributed to the incidence of increased outbreaks of insects and epidemic diseases that have further increased the probability of large-scale fires with greater stand-replacing capacity.

A given fire can burn with high or low intensity, depending on topography, weather, stand structure, and fuels. Fires usually burn hotter and kill more living trees if they burn upslope. They also burn hot where stand development or a previous disturbance has created a great amount of fuel, especially during dry, warm, and windy weather. Fires burn with low intensity during cool, damp weather or where they travel through areas of low fuels. Fires can predispose a stand to other disturbances. Low-intensity fires can weaken the trees by scorching the crowns, and making the trees susceptible to insect and pathogen attacks.

Fires of high intensity give competitive advantage to light-seeded tree species such as lodgepole pine and larch and to sprouting species such as grasses and forbs. True firs, which often regenerate from heavy seeds or from advance regeneration, are generally not favored. Low-intensity fires favor tree species, such as ponderosa pine, larch, and—to a lesser extent—Douglas-fir, that can endure fire. True firs are not favored by low-intensity fires.

Grazing and Browsing as Modifying Activities

Many centuries ago, eastern Oregon and Washington were probably subjected to grazing and browsing by many North American mammals that became extinct about 10,000 years ago (Martin 1967). Few elk were present in eastern Oregon and Washington from 1800 until about 1930 (Shay 1954, Thwaites 1905).

The relatively dry, warm summers and cold, moist winters of the eastside region have promoted open forest, forest interspersed with shrublands, grasslands, and a high percentage of nonforest vegetation. Bunchgrass vegetation as well as the rhizomatous sedges and grasses of the eastside plant communities are well adapted and stimulated by disturbance from grazing animals. Under controlled and managed conditions, these plant abundances in the community are enhanced by selective grazing by ungulates. As a result, this vegetation has provided an ideal habitat for ungulate species that depend on grains, grasslike plants, and shrubs for sustenance. Historically, a wide variety of ungulates occurred in eastern Washington and Oregon across the presettlement landscape. Early trappers speak of deer, elk, mountain sheep, antelope, and even bison in the valleys and canyonlands of the region (Evans 1991). These animals had wide ranging mobility, and coupled with their preferential use of the vegetation, caused moderate to light effects on vegetation. Natural predators, then more varied and numerous, helped keep ungulates in balance. As Euro-Americans settled the eastside region, many predators were displaced from their natural rangelands. As the domestic livestock industry gained prominence—first sheep at the turn of the century, then cattle in the 1930s and 1940s—the effect on native vegetation of too many animals too early in the season and for too long during the season became apparent.

Thresholds beyond which vegetation could not rebound were regularly surpassed by overgrazing on many rangelands of the east side. Accounts of ridgetops white with hundreds of sheep and dust lingering in the sky from cattle being driven across stock driveways are found in written accounts by the early administrators of the public domain (Tucker and Hall 1985). Significant upland areas on the eastside landscape have lost the capacity to support the native vegetation where livestock and wild ungulates once competed for fescues and other bunchgrasses. Streamside vegetation was also vulnerable because these areas were relatively isolated across landscapes of dry hills, canyons, and mountainous areas. Many meadows and stringers of grasses were irreversibly modified by the overuse of rangelands in the late 1800s and early 1900s.

Just as curtailing fire has brought a response by the vegetation to restore ecosystem balance, the lack of grazing animals in the bunchgrass ecosystem, coupled with the lack of frequent fire, has resulted in grassland decadence. The annual grazing of standing biomass by selective animals achieves a certain balance to the bunchgrass community by invigorating grazed plants and promoting dissemination and germination of the grasses. Grazing as a modifying activity has been generally perceived as negative as a result of the overuse by animals over too long a period of time. Highly productive sites have retrogressed to earlier seral stages and species richness has declined.

Insects and Diseases as Modifying Agents

Vegetation is not stable. Environmental factors influence eastside vegetation, which changes in response to disturbances within and among stands. When periods of stability are too extended for a vegetation that naturally receives periodic disturbances, instability is heightened. For example, if fire is not allowed to cause change, native insects, diseases, or both will. Lodgepole pine forests are historically replaced and rejuvenated by stand-replacing fires. In the Blue Mountains, lodgepoles live about 90 to 125 years, but in the early 1970s, foresters were surprised by wholesale tree mortality from mountain pine beetle damage. This shift from low beetle populations to outbreaks in eastside lodgepole pine forests was an ecosystem response to the lack of stand-replacement fires that recycle lodgepole pine stands before they become susceptible to bark beetles. In essence, the stands were over-aged, the trees were destined to die, and the beetle caused their mortality because fire (or harvest) did not. Lodgepole pine forests were not harvested because other forest products of greater economic value were being sought by industry.

Insect outbreaks have been reported since the late 1800s in eastern Oregon and Washington. The pine butterfly (*Neophasia menapia* Felder & Felder), the western spruce budworm (*Choristoneura occidentalis* Freeman), the Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)), the western pine beetle (*Dendroctonus brevicomis* Le Conte), and the mountain pine beetle (*D. ponderosae* Hopkins) have all had

major outbreaks; such outbreaks of native insects have probably always occurred in eastern Oregon and Washington when weather and stand structures were favorable to them. These outbreaks probably increased fuel loads and led to fires as well.

Many insects are host specific; consequently, insect outbreaks tend to favor the development of nonhost species. In mixed species stands, both nonhost species and young trees, which grow into newly available space, are favored. The young trees are often shade-tolerant true firs, which are highly susceptible to insects and diseases. Insect attacks often create snags which are favored by insectivorous birds. The dead stems also contribute to available fuels.

Glaciation

For tens of thousands of years, the continental glacier covered extreme northern Washington, and valley glaciers covered parts of the Cascades of eastern Oregon and Washington until about 12,000 years B.P. Since then, valley glaciers have advanced and retreated at different times, generally in response to climatic fluctuations. The cool period—the “little ice age” of about 1400 to 1850 A.D.—was a time of valley glacier advance. Since about 1850, these glaciers have generally been retreating (Lamb 1977).

Glaciers remove all vegetation in their paths, although trees and other vegetation sometimes remain on hills above valley glaciers. Retreating glaciers leave slopes of mixed rocks, sand, and little silt. Valleys where glacial meltwaters run often contain soils with high concentrations of boulders, gravels, and sands; the valleys are relatively unproductive for tens of thousands of years. Lakes form and ice dams break as glaciers retreat, resulting in floods of different magnitudes. Dry lake-bed areas of silts and clays are left in the wake.

The main effect of the glaciers in eastside landscapes was to establish a soil pattern of various productive sites on which species with differing competitive advantages grow.

Other Modifying Events

Although much less recognized than fire, grazing, insects, and diseases, other natural processes—windthrow, flooding, and erosion—influence the composition, structure, and age of vegetation on the landscape. Occasional windstorms reach high velocities and topple many trees, but winds also create small pockets of blowdown that leave canopy gaps where plants that need sun can grow. Root diseases, snow loading, and ice breakage often interact with wind in modifying stands.

Winds—Windstorms often break or uproot trees where the wind is channeled by local topography, and severe windstorms can overturn trees across large areas. Trees in overcrowded stands snap off or break at their root collars in windstorms or uproot, if they are on shallow soils. Trees blown over by winds create conditions that favor other disturbances such as insects and fires. Where only some trees blow over, the partial shade of remaining trees promotes shade-tolerant species such as true firs. Windstorms generally favor advance regeneration of true fir species in eastern Oregon and Washington. Windstorms create downed, woody material that favors some wildlife species, but it can also form barriers to the movement of large animals.

Floods and soil mass movements—Flooding, an annual feature of wetland ecosystems, is a natural, creative, and nurturing event to many wetlands communities. The infusion of new microsites for colonization and the delivery of nutrient-charged substrates ensures that these riverine or riparian communities will continue.

Erosion can produce changes beyond nature's abilities to rectify them. Erosion is part of an ongoing, sculpting process that provides landform patterns by deposition and mass-wasting activities. New landforms are continually created by rotational slumping, landslides, avalanches, and other debris-depositing events. The new landscape segments and patches enhance diversity and ecosystem health.

Floods and mass movement are considered undesirable because they silt reservoirs, displace river channels, undermine roads, and destroy property and human lives. But control of flooding and mass movement

have also reduced the input of sediments into streams, creating scoured stream channels free of sand and silt and of less use for many fish species. Floods and mass movements wash sediments into streams and stream channels, replenishing the gravel, sand, and silt in the stream and adding it to the floodplain soils. The riparian and aquatic animal and plant species that withstand siltation are given a competitive advantage, and other plants and animals are killed. Fish species are affected positively or negatively, depending on the frequency and time of year the sediment is added.

Climate Change—Within the last 1000 years, the climate became cooler, then warmer (fig. 16). Recent warming between about 1850 and 1940 led to stress among species that had begun growing under cooler climates at the warmer and drier extreme of their natural ranges (lower elevations and latitudes). Beginning in the 1930s (Franklin and others 1971), this natural warming also increased the upper latitudes and elevations at which species can grow, causing trees previously found at lower elevations to invade alpine meadows.

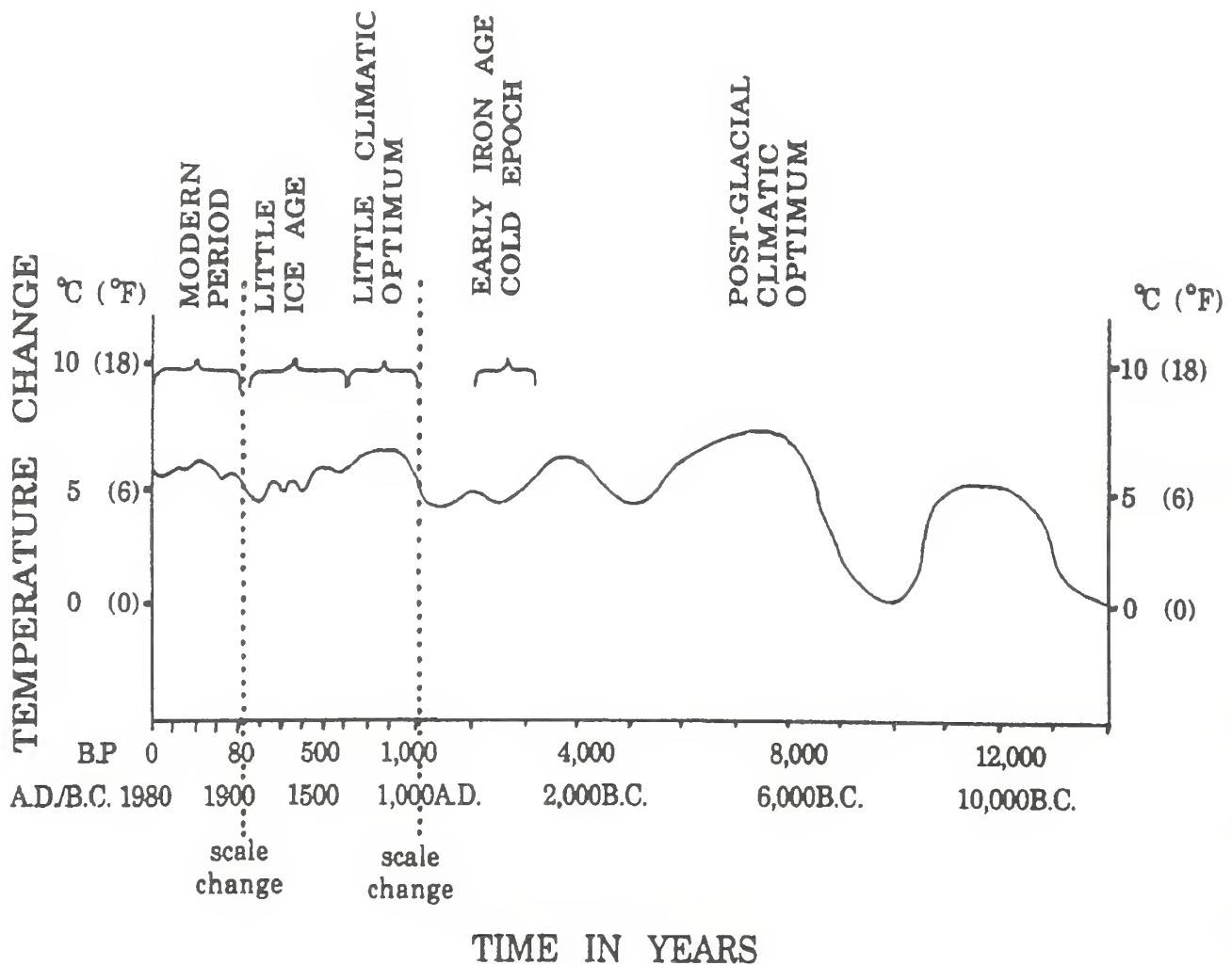


Figure 16. Average temperature variation in the northern hemisphere since the last glaciation (from Lamb 1977). Global climatic conditions have not been stable and have altered growing space and the species that are most competitive on a site (Oliver and Larson 1990).

MANAGEMENT-INDUCED DISTURBANCES

The natural disturbance regimes generally provide beneficial responses to the eastside vegetation. Plants that comprised eastside ecosystems have generally adapted to the effects of fire, grazing, and other disturbances. The long-term consequences of natural disturbances tend to enhance biological diversity.

The activities of human (especially Euro-American) occupation and industry modified to the natural order in ways both complementary and detrimental to eastside ecosystems. The effects of stand-scale treatments are often additive over time and space and therefore influence ecosystems at the landscape and watershed scales.

Harvesting

Western expansion repeated the treatment of forests by Euro-Americans as they crossed the continent to the Pacific Northwest (Billington 1967). The eastside forests were exploited along major valleys and around centers of population as industrial growth consumed forest products from the 1860s to the 1920s. Public lands provided commodities for a new western-based society. In the 1930s, 1940s, and 1950s, forest practices were essentially along streamcourses and roads built for extractive activities. Silvicultural practices were usually selective or for salvage and represented conservative use of timber resources.

Starting in the 1960s, and coming to fruition in the 1970s, changes in forest management philosophy and practices dramatically accelerated the volume of timber products being removed from the forests of the eastside. The active curtailment of fire for more than 50 years had allowed the ingrowth of fire seral and climax tree species to overstock forest stands that had received periodic underburning or stand-replacement fire. As a novel practice for the eastside, the large-scale removal of slower growing, older trees was promoted by intensive thinnings of small-dimension trees, as a way of reducing stocking and encouraging rapid wood-fiber growth on the residual trees. The first clearcuts were performed in many areas of the eastside region during the 1970s, where stand replacement was deemed necessary for sanitation and rejuvenation of a thrifter forest. Also, total tree-overstory removals became a common practice to harvest ponderosa pine trees that had ceased to grow at increments acceptable to silvicultural guidelines for site capability and to allow better growth of residual trees. Thus, many acres of parklike ponderosa pine forests, which had become dense from grand fir, Douglas-fir, and pine saplings and pole-sized trees as a result of fire exclusion, were now converted from pine dominance, through management practices, to greater dominance of firs.

For the most part, fire was not employed as a silvicultural tool during this period. If stocking was not adequate from the ingrowth under the older trees, nursery stock was planted. Seedbearing trees were generally removed for wood instead of being left to provide future progeny. Without fire as a promoter of seedbeds for pine seedlings, these sites became more conducive to fir. In the 1980s, with stocking still too high for thrifty, vigorous trees and with forest composition different from what it had been, the populations of insects, both defoliators and bark beetles began to rise.

Today, with many acres of severely diseased and defoliated trees throughout the eastside forests, the public has questioned the management of both public and private forests. Professional land managers and specialists have joined with natural-resource scientists to determine how to improve forest health (Gast and others 1991). After several years of intensive study and communication, several initiatives have emerged to improve the forests.

Management has shifted from even-aged and single species stands to uneven-aged management promoting seral fire species (ponderosa pine, Douglas-fir, and western larch). A concerted effort is being made to reintroduce fire into the forest ecosystem with prescribed natural fire and planned ignitions. Management focus has shifted from the stand to the landscape scale. And land management agencies have championed assessing and managing ecosystems rather than forest commodities and benefits (Overbay 1992, Robertson

1992). This ecosystem focus has diminished the emphasis on extractive activities and heightened the awareness of how sensitive various ecosystems are to management activities.

Part of the work of the 1990s and beyond the turn of the century will be restoration and rehabilitation of landscapes and ecosystems. Some of the disturbances created in this accelerated extractive period were too severe for the sites and have caused successional shifts that took the vegetation beyond thresholds to stages where later seral vegetation cannot return, either because basic habitat elements (soil, water) or plant disseminules have been lost.

Overgrazing

Perhaps livestock grazing has caused the greatest degree and extent of disturbance on the east side. The mobility of the various ungulates across western rangelands has affected virtually all segments of the landscape to some extent. The effect has been greatest along watercourses, in basin meadows, and on ridgetops, where stock driveways and bedding grounds were used season after season for many years. The degrading of native vegetation in these areas has been so complete that thresholds were passed, leaving disclimactic vegetation. This “new” vegetation is usually either simpler biologically than the native flora, or composed of invasive, less desirable or noxious plants.

Examples of communities resulting from overgrazing sites that can support communities of climax Idaho fescue (Idaho fescue plant associations) are now devoid of any bunchgrasses. Severely overgrazed ridgetops where fescue once dominated are now growing much simplified communities. Deeper soils carry dense stands of cluster tarweed (*Madia glomerata* Hook) which inhibits germination and establishment of other plants by exuding resins (Carnahan and Hull 1962, Hull 1971). Shallower soils on these sites may contain noxious populations of gumweed (*Grindelia* spp.), pussytoes (*Antennaria* spp.), or knotweeds (*Polygonum* spp.).

Meadows have been severely affected to the extent that investigating ecologists often have no clues to predict what the native vegetation might have been. Examples of invasive communities that have overtaken eastside wetlands are terraces dominated by Kentucky bluegrass (*Poa pratensis* L.), big sagebrush flats, and annual brome (*Bromus* spp.) grasslands. Incising the fluvial channel to greater depths as a secondary result of the overgrazing activities has reduced the availability of moisture to the meadow vegetation and permitted invasion by more xeric plants.

Native American and Euro-American Fire Setting

Although the extent and intensity of fires before Euro-American settlement is unknown, accounts by fur traders, explorers, missionaries, and early immigrants say that fires were actively set throughout the eastside forests and grasslands to improve rangelands for livestock and to help in hunting game (Evans 1991). The early settlers also used fire to clear land and promote nonforest vegetation, irretrievably altering the principal valleys where the combination of settlements and agricultural pursuits rapidly replaced the native vegetation.

The settling of the West gradually reduced the influence of fire in periodically modifying vegetation. With the diminishing of the Native American presence and life style and as meadows and grasslands were converted to farmlands, fire gradually declined. Because the young settlements were at risk to wildfire, prevention was politically stimulated. Fire was not recognized as an integral part of the natural cycle in the intermountain Pacific Northwest landscape.

Other Induced Disturbances

Mining, railroad logging networks, roadbuilding, dams, and agriculture all combined to dramatically alter the eastside landscape. Where these activities were conducted—in streambottoms, along river terraces, and on the most fertile lands of the region—native plant communities have generally been replaced by exotic or invasive communities.

THE ECOLOGICAL ROLE OF DISTURBANCE

The Steady-State Paradigm of Ecosystem Development

Disturbances have long been recognized in forest ecosystems; however, their significance was not appreciated as long as scientists maintained the view that forests consisted of stable, coevolved tree species that develop through succession toward a steady-state of specific climax species and structures (Oliver 1992a).

Belief in this steady-state forest has led scientists and others to assume that undisturbed forest structure or development pattern is natural and therefore conducive to sustaining biodiversity and sustainability. The steady-state paradigm of forest development has prevailed at different times in the thinking of foresters, conservationists, ecologists, and politicians for some parts of the past century. The paradigm has led to the management policy of stopping all fires, to the ecological theories of disturbances destroying a steady-state ecosystem, to the conservation policies of reducing clearcuts and trying to stop stream siltation events, and to the political assumption that stopping all human activities in the forests will mitigate the loss of endangered species.

The steady-state paradigm for forest ecosystems has lost credit among plant ecologists during the past two decades (Oliver and Larson 1990, Pickett and White 1985, Stevens 1990); however, it is still assumed to be true among those who learned earlier ecological theories and have not kept abreast of the science. Ecosystem management requires that management, laws, and organizational systems be based on accurate concepts of dynamic forests where the role of disturbances—both natural and human—are appreciated.

Competition as the Primary Interaction Among Tree Species

The primary interaction among tree individuals and species is competition. Under various circumstances, different species gain competitive advantage and are able to survive and dominate a forest landscape. The same area may be dominated at one time by grasses and shrubs, at another time by ponderosa pine trees, and at another time by grand fir trees. Some plant and animal species survive primarily during the first few decades after a disturbance, and others survive primarily in forests with no or minor disturbances. Old forests have no inherent desirability, stability, or naturalness; nor is a single forest structure or domination by certain groups of species more inherently natural than others. As in all areas, forests observed in eastern Oregon and Washington in the short time of recorded history are simply the result of those species present and most competitive in the conditions during this period.

The Concept of “Growing Space”

Trees compete for such growth factors as sunlight, moisture, nutrients, and soil oxygen, which we refer to simplistically as “growing space” (Oliver and Larson 1990). Plants establish and grow where their basic environmental needs are met. When they grow together, they compete for the same or similar growing space.

The growing space of an area fluctuates so regularly day by day and seasonally that plants have adapted their diurnal and annual cycles to it. When plants have grown in an area until their roots have completely occupied the soil or their foliage is blocking all available sunlight, the growing space is said to be filled. After the space is filled, one plant can only increase its growing space by taking it from another plant through competition.

Factors Influencing Species Domination

The plants that have the most growing space at a given time and place appear to dominate the area. Various tree, shrub, and herbaceous species are able to dominate the growing space because they survive in an area and have competitive advantages under specific species, climate, soil, and, disturbance regimes. The regimes are discussed on the next page:

- ❑ Species presence. Species are constantly migrating into and out of a region. A species has the opportunity to dominate an area at a given time only when a species is present in a region and can survive under the specific soil, climate, and disturbance regime existing at that time.
- ❑ Climate. Each species has a range of climatic conditions under which it can grow. These climatic conditions usually restrict each species to a combination of latitude and elevation zones (fig. 17). A species usually grows most vigorously near the middle of its suitable range of climatic conditions. A species is most sensitive to the climate when it is initiating and undergoing intense competition shortly after a disturbance (as will be discussed later.) The climate of the Pacific Northwest (and elsewhere) has fluctuated, and continues to fluctuate, at shorter intervals than the lifespan of trees (fig. 16); consequently, a species' presence at a specific location is partly indicative of the climate when the species became established.

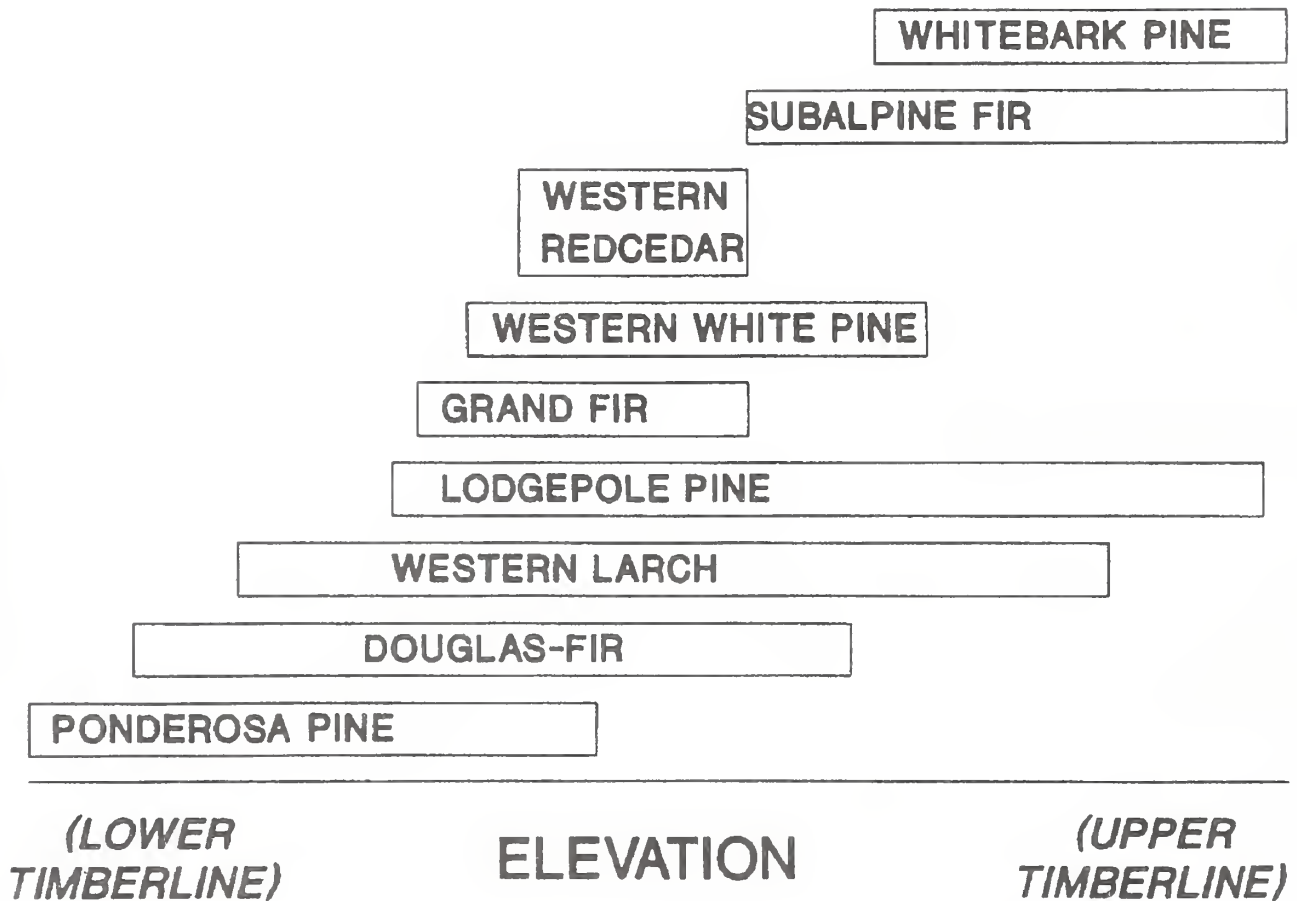


Figure 17. Distribution of tree species along a gradient of elevation (also indicating climate) in the northern Rocky Mountains (after Adams 1980).

If the climate changes enough to be outside the species' range of tolerance while it is growing in an area, the species may become weakened and susceptible to various insects and diseases. Insect and disease buildups in certain places in eastern Oregon and Washington may be the result of the changing climate. Because climate has changed and will always change for natural (and some human-caused) reasons, weakened trees will always exist at the extreme ranges of species.

- ❑ Soil. Nearly all species grow most vigorously in moist, well-drained soils within their climatic range; however, certain species are able to compete well on dry or poorly drained soils. For example, grand fir grows extremely vigorously on moist, well-drained soils and outcompetes other species there under most conditions (fig. 18).

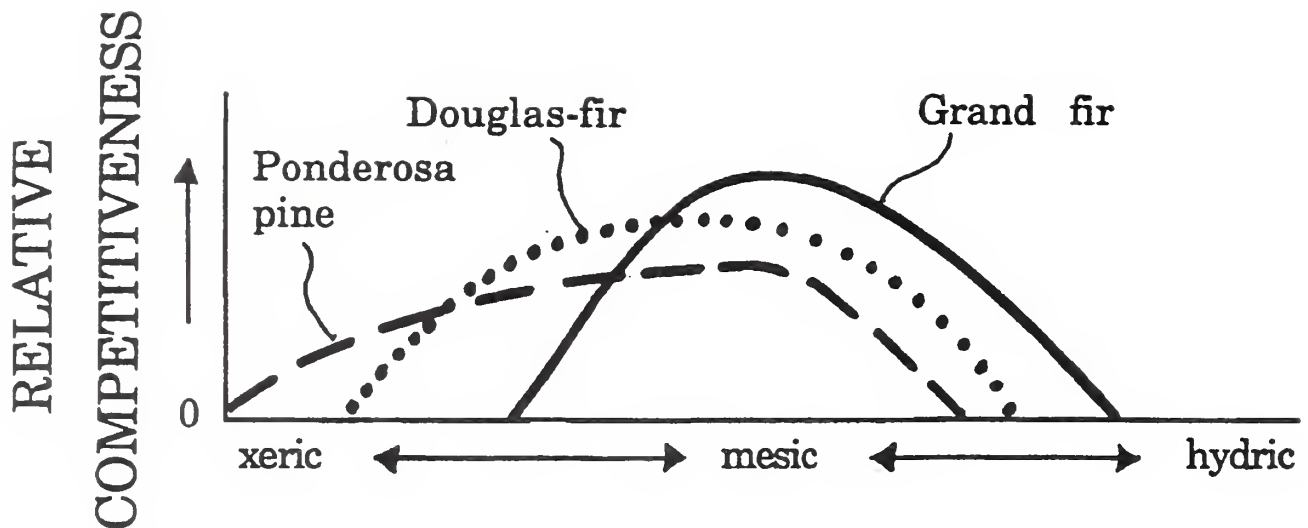


Figure 18. Most tree species grow best within a relatively narrow range of moist, well drained (mesic) soils; however, some species can tolerate more extremes of dry (xeric) and wet (hydic) soils and outgrow other species. Consequently, tree species dominate and are found where they compete successfully, not where they grow best (after Oliver and Larson 1990).

At the other extreme is lodgepole pine, which also grows best on moist, well-drained soils but generally cannot compete very well on sites with grand fir or other tree species. It can outcompete most other species on extremely dry soils or soils with frosts; therefore, it is usually found on these soils—not where it can grow best, but where it can compete successfully.

If a species can compete in soils poorer than those where it usually outcompetes other species, it exists in a stressed condition that renders it susceptible to insects and diseases. Some species have gained a competitive advantage on poor sites, and so became susceptible to insects; insect outbreaks and disease epidemics have always been present in portions of the forests.

- ❑ **Disturbances.** Various natural and human disturbances affect forests (White 1979, White and Pickett 1985). Fires, windstorms, floods, insect attacks, diseases, soil slumping, avalanches, volcanic activity, and grazing and browsing have been common to eastern Oregon and Washington before recent (1840s and later) population increases. Settlement of the region changed the frequency of these natural disturbances and added farming, increased grazing and browsing, timber harvest, and mining.

Disturbances and Growing Space

Disturbances eliminate some or all plants from an area. Disturbances to forests are usually not so severe as to damage the soil; by killing some plants, they open growing space to other plants (Oliver and Larson 1990). Plant species may gain a competitive advantage after a disturbance in one of two ways: they may endure the disturbance (while their competitors cannot) and thus grow into the released growing space immediately after the disturbance, or they may germinate or otherwise initiate after the disturbance and thus occupy the growing space before competitor individuals and other species. Specific details of the type of disturbance gives one species or another a competitive advantage.

Type of Disturbance and Species' Ability to Endure it

If the disturbance is not too severe, certain species are able to endure it (Oliver and Larson 1990). For example, thick-barked ponderosa pine trees and, to a lesser extent, Douglas-fir trees, are better able to endure ground fires, except at the seedling stage, than are thin-barked true firs (grand and subalpine).

Aspen trees generally endure floods and siltation better than other species by adding adventitious roots up their stems. Certain shrubs and herbs avoid damage from grazing and browsing by being unpalatable or thorny. Insects and diseases are generally somewhat host specific; consequently, the resistant species will gain a competitive advantage when a certain type of insect outbreak or disease epidemic occurs. Ashfall from volcanic eruptions tends to affect true fir species more than it does Douglas-fir trees. More recently, selective harvesting, a frequent silvicultural practice in eastern Oregon and Washington, tended to leave (and therefore favor) species of low timber value—true firs, for example.

Type of Disturbance and Regeneration Mechanisms

Disturbances that do not allow a species to endure may give the species a competitive advantage in the long run. Different species regenerate by one or several of a variety of mechanisms, and each mechanism gives the species a competitive advantage after certain types of disturbances. For example, landslides, erosion, very heavy grazing, and farming—which destroy root systems, stumps, and buried seeds—give the competitive advantage to species that regenerate from light seeds because they enter the area rapidly after the disturbances. Less severe disturbances, such as fairly intense fires, give the advantage to species that can regenerate from buried, dormant seeds, root sprouts, rhizomes, and tubers. Slightly less severe disturbances, such as cool fires or light grazing, give the competitive advantage to species that regenerate from stump sprouts, tubers, and stolons; even less severe disturbances, such as windstorms and avalanches (in the run-out zone), give the competitive advantage to advance regeneration. (Advance regeneration consists of understory individuals that germinate in a relatively closed forest and grow little for the ensuing decades; for example, some fir advance regeneration can be less than 2 feet tall and over 50 years old. On removal of the overstory, however, advance regeneration can often grow rapidly and dominate, providing it is not destroyed in the disturbance that removes the overstory.)

Disturbance Frequency and Forest Growth

Disturbances range from very frequent to very infrequent, depending on the predisposition of the stands and conditions surrounding the disturbance agent. The stand's development pattern can sometimes set up another disturbance, thus influencing the disturbance frequency and type. The frequency of a disturbance can sometimes be indirectly related to the intensity of the disturbance. Different disturbances can also interact within a stand, with one disturbance either increasing the probability of another disturbance, or compensating for its absence.

Fire, disease, insects, wind, and grazing disturbances can be greatly affected by the condition of the stand. For example, a stand is often susceptible to an intense fire soon after a fire or other disturbance has killed many trees and the dead stems and twigs have dried. If the stand does not burn then, it becomes more susceptible after density-dependent mortality has created dry fuel (the stem-exclusion stage, to be discussed later). If the stand does not burn then, it sometimes becomes less susceptible as this mortality slows and a green understory develops. Stands are often susceptible to diseases, insects, and wind when they have grown very densely and the trees have become crowded as they increased in height. This crowding reduces diameter growth and physiological resistance, which makes the trees susceptible to buckling or blowing over in windstorms as well as to attacks by insects and diseases. A stand of tree seedlings is more susceptible to damage from grazing and browsing soon after a disturbance that has resulted in many forage plants growing within reach of grazing and browsing animals. Once the trees in a stand have grown more than 5 or 6 feet tall and have killed shorter shrubs and herbs through shading, the site is of less value for grazing and browsing animals for many years.

The frequency of some disturbances can be indirectly related to their severity, if the underlying factors affecting disturbance severity increase with time. For example, the severity of fires, soil slumping, wind events, and insect outbreaks is somewhat directly related to the time since the last similar disturbance. Where fires are absent for a long time, a large amount of fuel can accumulate; then, the burn would be extremely hot. Similarly, a stand's susceptibility to insects can increase with time. Insect outbreaks are

greater when small, frequent outbreaks have not reduced the amount of susceptible trees. The tendency for soil slumping is especially high near stream channels, with the size of each slump increasing as the time since the last slump increases.

On the other hand, the magnitude of floods, grazing, and volcanic activity is not directly related to their frequency. Floods are primarily related to rainfall, snowfall, and winter warming periods. Grazing is related to the number of animals, sometimes a direct (rather than indirect) relation to the amount of previous grazing. Volcanic activities are geologic events and are generally independent of previous activities.

Disturbances may result in stands that are either more or less susceptible to other disturbances. For example, windstorms and insect outbreaks and disease epidemics make stands more susceptible to fires. Similarly, fires sometimes make stands more susceptible to insect outbreaks. Under extreme conditions, fires or harvesting can make a hillside more susceptible to soil slumping, although the slumping would occur eventually anyway. Harvesting can make floods more extreme, although very extreme floods occur independently of forest harvest conditions.

Some disturbances make stands less susceptible to other disturbances. For example, appropriately implemented forest harvesting can make stands less susceptible to fire, insects, diseases, and windthrow as well as flood events. Fires can make stands less susceptible to insects, diseases, and windstorms.

Disturbance Size

In the recent history of eastern Oregon and Washington, disturbances have ranged from less than an acre to several hundreds of thousands of acres. Size and location of a disturbance partly depend on the type of disturbance and partly on soils and topography, stand structures, weather, and other conditions.

Certain types of disturbances occur in predictable areas. Floods generally occur in low-lying areas and avalanches on high mountains. Windstorms often are more frequent where mountains channel winds. Insect outbreaks occur where certain soils, in combination with specific stand structures, create stressed trees. Fires vary in intensity with topography and stand structure. Areas of intense grazing vary with species, animal populations, and stand structure. Most domestic and wild species graze over a range of elevations—at high elevation areas in late summer and lower elevations in spring, autumn, and winter.

The extent of a disturbed area is, therefore, influenced by the area's topography and stand structures. A large, contiguous area of similar stand structures will allow a disturbance to cover a large area. Similarly, once a single disturbance has covered a large area, it will promote similar species and lead to similar stand structures, which can again become susceptible to a single, large disturbance. In this way, disturbances of a given size can be somewhat maintained once a pattern is begun.

STAND DEVELOPMENT PATTERNS AND PROCESSES AFTER DISTURBANCES

Relay and Initial Floristics Patterns of Development

Two theories on successional patterns of development are called "relay floristics" and "initial floristics" (Egler 1954). Forest (or other vegetation) regrowth after disturbances has often been assumed to follow a pattern of some early (pioneer) species invading soon after the disturbance and creating microenvironments favorable for other species to invade later. These late-arriving species then create favorable conditions for still other species to invade, until one or several species are able to create conditions that maintain themselves in a "climax" condition. This pattern of sequential invasion has been referred to as relay floristics.

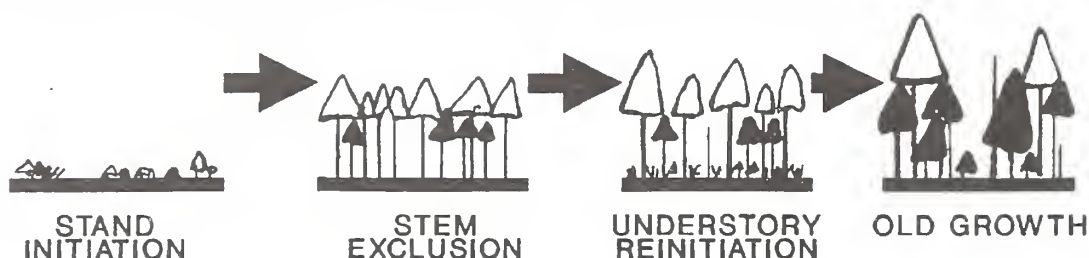
Instead, a pattern of initial floristics generally occurs, where those plants that gain a competitive advantage soon after the disturbance continue to dominate the stand for many years. Consequently, the same area may be dominated for long periods by grasses, shrubs, or any of several tree species or combinations of species, depending on which gained the initial advantage (Drury and Nisbet 1973, Oliver and Larson 1990).

Development After Disturbance

Disturbances create a range of conditions in eastern Oregon and Washington forests. At one extreme, a disturbance can be stand-replacing (or major); all previous trees are destroyed and new trees develop with no influence from trees that grew there before the disturbance. A disturbance can also leave various amounts of older trees in a stand. Disturbances that do not destroy all previous trees are referred to as partial (or minor) disturbances (Oliver 1981).

Forest development in eastern Oregon and Washington will be described for two types: development after stand-replacing disturbances and development after partial disturbances, although a gradient exists between these two types of forests. Stand structures change dramatically after both stand-replacement and partial disturbances (fig. 19). Many variations of these stages are possible and each stage can be subdivided (Oliver 1992b).

A. DEVELOPMENT AFTER STAND-REPLACING DISTURBANCE



B. DEVELOPMENT AFTER PARTIAL DISTURBANCE

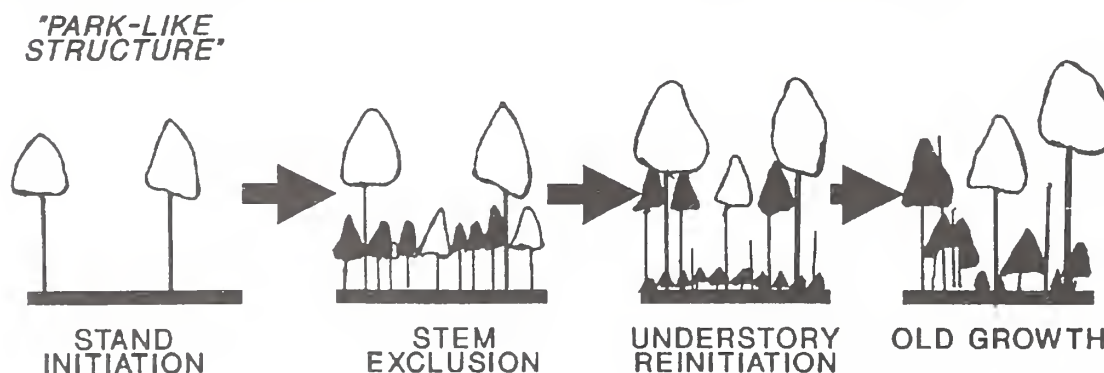


Figure 19. Stands in eastern Oregon and Washington developed after both stand-replacing disturbances and partial disturbances. Stands change through a variety of structures as they grow after a disturbance. Each structure is suitable for some animal species and not others. White tree crowns represent shade-intolerant species (such as pines and larches); dark crowns represent more shade-tolerant species (such as grand fir and Douglas-fir).

Forest Development After Stand-Replacing Disturbances

Some examples of stand-replacing disturbances are intense fires, windstorms, clearcut harvesting, clearing for farming, floods, and siltation events (Oliver 1981, Oliver and Larson 1990). Reburns or fires that follow windstorms, insect outbreaks or disease epidemics, or partial cutting operations can be especially hot fires and often are stand-replacing disturbances.

Stand-initiation stage—After a stand-replacing disturbance, the growing space becomes available and a variety of species initiate from regeneration mechanisms favored by the preceding type of disturbance. The initiating stems expand and occupy the growing space above and below ground. This stage often contains the most numerous species of plants and animals.

Many plants flourish during this stage because none have gained a competitive advantage and excluded the others. Many animals are also present because a great variety of vegetation species and structures are accessible from the ground. Stands in this stage are generally suitable for grazing and browsing species and their predators. The lynx partly depends on this stage because it preys on the rabbits that feed on the low herbs and shrubs. Stands in this stage are resistant to most disturbances except grazing and fires. The stand-initiation stage can last for many decades on poor soils where plant species invade and dominate very slowly. Individuals that initiate after the same disturbance are referred to as being in the same cohort (Oliver and Larson 1990). (Cohort is used here instead of age-class because of the possibly varied and wide age range the trees may have.)

Stem-exclusion stage—Eventually, the growing space is completely occupied by the plants. The more competitive plants both exclude others from invading and take over the growing space of the less competitive plants. Forest stands often lack vegetation near the forest floor because vigorous tall trees have outcompeted smaller shrubs and herbs for light. Where two or more tree species compete, one will often grow taller than the other and cause the shorter one to grow very slowly in a lower layer or stratum (fig. 20). As the taller trees continue to grow vigorously in full sunlight, the differences in sizes between trees in the two strata become more pronounced. The small size of trees in the lower stratum trees has led scientists to mistakenly assume they are younger, and either that relay-floristics succession is occurring or that a second, partial disturbance has occurred in the stand. This stratification pattern has been observed in several species mixtures common to eastern Washington and eastern Oregon.

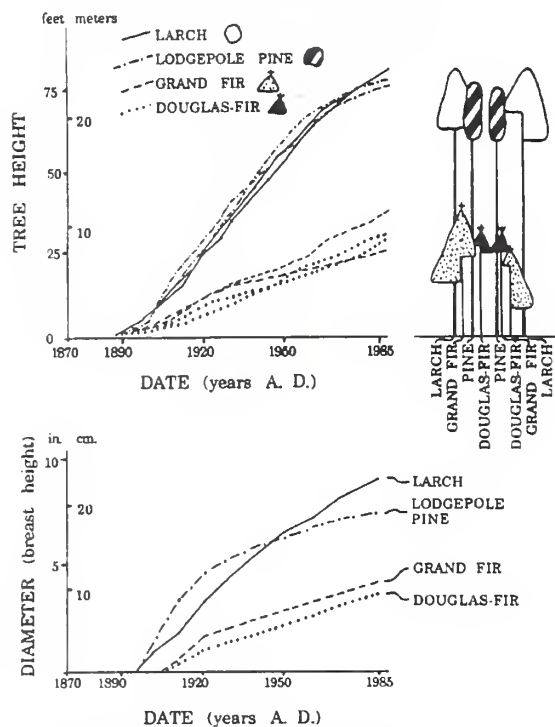


Figure 20. Development of a mixed-species stand in the eastern Washington Cascades after a fire in about 1885. Faster early growth rates allowed larches and lodgepole pines to outgrow and suppress growth of Douglas-firs and grand firs. The stratified (layered) appearance and differences in size have led ecologists to assume incorrectly that the smaller trees are younger and developing as a steady-state, climax component in the stand (Oliver and Larson 1990, from Cobb 1988).

This stage is usually least diverse for plant and animal life. Some trees become suppressed as others gain the competitive advantage. The suppressed trees, slow in diameter growth, become susceptible to insects, winds, and diseases, and often die. Stands in this stage are quite susceptible to fires because of the dry, dead, and suppressed trees and lack of moist, living vegetation on the forest floor. They are even more susceptible to fires if they have had wind, insect, or disease outbreaks. If trees in this stage are overcrowded because of their initial invasion pattern, they may never grow large in diameter. The stem exclusion stage can last for many decades, provided the stand is not destroyed by a disturbance.

Understory reinitiation stage—If the stand is not completely destroyed by a disturbance, the overstory trees eventually lose their ability to dominate the site completely through crown abrasion and other mechanisms (Oliver and Larson 1990). Shrubs and trees that invade the understory grow very slowly in height for many years and form advance regeneration. This stage contains a greater variety of plant and animal species than the stem exclusion stage, but fewer than the stand-initiation stage. Stands at this stage can be used for hiding cover, thermal cover, and foraging; they are often less susceptible to fires than those in the stem-exclusion stage. Provided it is not destroyed by disturbances, this stage can last for several hundred years.

Old-growth stage—Barring large partial or stand-replacement disturbances, the forest continues to grow until eventually the overstory trees die. As they die, understory trees formerly existing as advance regeneration often grow to the overstory. The result is a structure with many layers of foliage, a diversity of tree sizes, and large standing and downed woody material. This structure is not always attained where stands develop without disturbances, however.

Stands in the old-growth stage often become susceptible to diseases, insects, and windthrow. A diversity of plants and animals usually live in forests during this stage—often as much diversity as in the stand-initiation stage. These species, however, are usually different from those living in the stand-initiation stage.

Forest Development After Partial Disturbance

Examples of partial disturbances are fires, windstorms, and harvesting other than clearcutting (Oliver and Larson 1990). After partial disturbances, patches of growing space are released, and the newly invading cohort undergoes changes similar to the stages described after “stand-replacement” disturbances. The invading individuals, however, compete both with other invading plants of the same cohort and with trees of older cohorts that survived the disturbance. As in stand-replacement disturbances, the type of partial disturbance helps determine which species first gain the competitive advantage.

Soon after the partial disturbance (and especially if the disturbance destroys much of the previous cohort), a large variety of plant and animal species and greater structural diversity are found than in the stand-initiation stage of single cohort stands. Stands of this structure, once common at lower forest elevations in eastern Oregon and Washington, were kept open by the partial disturbance of repeated small fires and grazing. The older cohorts were primarily fire-resistant ponderosa pine and Douglas-fir trees. These parklike stands are very resistant to disturbances other than ground fires.

During the initial growth of the younger cohort, it excludes many shrub and herb species. As it grows taller, the initial diversity of plant and animal species is lost. The older cohort or cohorts shade the newly invading plants, giving an advantage to shade-tolerant species in the younger cohorts. True fir species (and to some extent Douglas-fir trees) are generally the shade-tolerant species in eastern Oregon and Washington. On droughty sites, these trees can reduce the vigor of overstory Douglas-fir and ponderosa pine trees, increasing their susceptibility to insects and diseases. The younger cohort of true firs are also very susceptible to insects, diseases, and mistletoes. As they grow, they also create large amounts of dry biomass which make the stands susceptible to stand-replacing disturbances.

As the older and younger cohorts grow, they often resemble stands in the old-growth stage and contain the old-growth structural features. They contain many species common to stands with many strata, mistletoe, hollow trees, and logs.

FOREST PATTERNS COMMON IN EASTERN OREGON AND WASHINGTON

Forests of all structures (fig. 19) can be found in eastern Oregon and Washington. Because of the disturbance history, however, some structures are more plentiful and others less plentiful than they have probably been during the past 100 years.

Fewer stands have parklike structure at low and middle elevations now than in the past because the exclusion of fires has allowed these stands to grow to the stem-exclusion structures. These stands have become susceptible to stand-replacing insect, disease, and fire disturbances or a combination of them.

Probably fewer stands are in the understory re-initiation and old-growth stages at middle elevations than in the past. In addition, stands in the old-growth stage probably have smaller, less vigorous trees in the older cohorts. These changes are because past harvesting practices have promoted true fir species and retained nonvigorous, often diseased or scarred trees. These stands are now susceptible to stand-replacing disturbances from insects, disease, fire, or all three.

Probably slightly fewer stands at the upper elevations are in the understory re-initiation stage, and more in the parklike stage at present because recent shelterwood harvesting has favored this structure. The parklike structure is resistant to many disturbances and, where the older cohorts do not cast too much shade, should grow to vigorous stands in the older stages.

Many more stands are probably in the stem-exclusion structure at all elevations because of stands regrowing after the large fires and the abandonment of grazing between 1890 and 1940. In addition, regeneration practices were to plant trees close together during the 1950s and 1960s. Many stands in the stem-exclusion stage are overly dense and becoming susceptible to fires, windthrow, and insects. Because the trees are overcrowded, they probably will not grow to large diameters.

LANDSCAPE PATTERN, STAND STRUCTURE, AND WILDLIFE

The interactions of disturbances, topography, and climatic regions tend to create stands across a landscape of relatively uniform growth potential, species composition, disturbance history, and structures. A landscape area is comprised of stands that form a mosaic of structures. The pattern to the mosaic of structures then dictates which species survive and how they migrate among areas as well as how fires, insect outbreaks, and similar disturbance agents move across the landscape.

Direct and indirect evidence suggests that before the active settlement period, a relatively small landscape area, such as 15,000 acres, did not contain a balance of the stand structures in figure 19. Large fires, insect outbreaks, grazing, timber harvesting, and other disturbances covered many such landscape units, which created many stands with similar structures. Such large disturbances did not, however, affect all stands in all landscapes. The disturbance missed some area—for various topographic and other reasons characteristic of the disturbance. These missed areas contain stand structures distinctly different from the predominant ones.

Immediately after a large disturbance, the landscape probably consisted of a matrix of most stands in the stand-initiation stage, with isolated pockets of stands with the other structures (Camp and others 1993). Shortly after the disturbances, species that occupied this structure proliferated and expanded, with suitable genetic mixing within landscapes to maintain a diverse genetic base. As the stands grew, open structures suitable for these species were reduced; the species diminished through death, emigration, and low germination rates.

As the matrix of most stands grew to the stem-exclusion stage, species that required the stand-initiation stage became restricted to relatively small, isolated open areas. As the matrix grew older, species that had previously been restricted to closed forest structures expanded into the matrix, increased in number, and genetically mixed with individuals in previously isolated parts of the landscape. Disturbances and re-growth continually changed the structures in the matrix somewhat randomly. Over large areas, however, all structures and populations were maintained.

Across the landscape, therefore, populations that require a variety of structures predominate at different times and then become reduced and confined to small areas as unfavorable stand structures predominated. This fluctuating pattern allowed many species with conflicting requirements to avoid becoming endangered through permanently fragmented landscapes.

Eastern Oregon and Washington now contain relatively few open and parklike structures; species such as the goshawk and lynx that use them are relatively few and endangered. At the same time, the many old-growth structures provide habitat for the spotted owl. The proportions of structures will change again as they always have; however, whether they change randomly through natural disturbances, which may not create refugia, or through controlled disturbances that maintain and control areas of refuge depends on how successfully ecosystem management can be implemented.

SUCCESSION

Vegetational succession is the unidirectional change in species proportions of a stand or the complete replacement of one community by another (Daubenmire 1968). It is the process of species establishment, development, and replacement within a community. Primary succession is the change that occurs on a surface recently bared by physiographic processes such as lava flows, glacial retreat, and erosion (Daubenmire 1968). After colonization and vegetational development of such sites, subsequent disturbance initiates a sequence of vegetation change defined as secondary succession. In secondary successional seres, change is initiated by disturbance agents (such as fire, insects, wind, flooding, logging) that affect preexisting vegetation.

Smith (1982), Franklin (1982), and Farrell (1991) have suggested that succession is a complex process with a multitude of mechanisms and patterns yet to be analyzed and described. A view of succession has emerged that is driven by life histories of individual species, autecological attributes, and by chance elements (Franklin 1982, West and others 1982). A strictly deterministic model of the natural process has evolved to a model in which elements of uncertainty drive both biotic and abiotic interactions (Christensen 1988).

Connell and Slatyer (1977) described three successional models dependent on species interactions during establishment and development of postdisturbance populations: the tolerance model—early successional species interaction with mid- and late-successional species is minimal with no effect on the establishment of later colonists; the facilitation model—early successional species interact with later ones and hasten their establishment; inhibition model—early successional species interact with later successional species and slow their establishment (Farrell 1991). Along this interaction gradient, specific mechanisms of successional change should be identified and described to promote understanding of inland Northwest ecosystem dynamics.

Successional pathways depict the probable course of community development within a framework of defined community types for a disturbance regime. If the natural disturbance regime is altered in type, frequency, duration, intensity, scale, or reliability (Rykiel 1979) or management effects on ecosystem components are modified through technological evolution, the successional sere may also change. Altered abiotic and biotic interactions may lead to different expressions of individual plant species responses and the identification of different successional pathways. Predictability of ecosystem responses may suffer unless new interaction data are incorporated into a more complete model of successional change.

Knowledge of plant succession is the foundation of sound vegetation management where the primary goal is to retard, arrest, or accelerate the natural forces of vegetation change. Detailed descriptions of the target plant communities, their probable developmental pathways, and site-specific habitat factors (that is, soils, geology, slope, aspect, elevation) can assist in identifying alternatives for management objectives and vegetation units.

Steele (1984) and Arno and others (1985) proposed approaches to classify succession of intermountain and northern Rocky Mountain forest vegetation, respectively. Clausnitzer (1992) described a successional classification of grand fir plant associations of northeastern Oregon and southeastern Washington. These efforts describe the temporal variation in plant association structure and composition and promote the understanding of western forest ecosystem dynamics.

Steele and Geier-Hayes (1987, 1989, 1992) presented dominant plant species responses to disturbance agents such as scarification and broadcast burning, common to forest regeneration activities. Arno and others (1985) described community responses within a framework of similar disturbance factors, including wildfire. The Northern Forest Fire Laboratory created a database of species' autecological characteristics, including fire response, for many tree, shrub, grass, and forb species of the intermountain West. The latter effort should be broadened to include information for more Pacific Northwest species' responses to varied disturbance regimes.

Community responses to a single disturbance have often been studied, but variations of community responses to several disturbance regimes should also be analyzed. The elements of a regime (type, frequency, duration, intensity, scale, and reliability) would vary the interaction of these elements across community types. Compositional and structural changes are the interaction of the disturbance regime with the plant community components at the time of disturbances. Describing this interaction at the scale of successional classification is appropriate.

LANDSCAPE ECOLOGY

A landscape is a heterogenous land area with a cluster of interacting ecosystems as repeated components throughout. The study of three landscape attributes, structure, function, and change, are the foundation of landscape ecology (Forman and Godron 1986). Landscape development is driven by five factors linked directly and indirectly to one another. Climate is the major controlling factor of landscape pattern. Soils, geomorphic processes, animals, and vegetation are all linked to each other and climate. Disturbance, interacting with these abiotic and biotic factors, produces landscape heterogeneity (Forman and Godron 1986).

Landscapes have three structural elements: a matrix, patches, and corridors. In forested landscapes, the matrix is defined as the most contiguous vegetation type. Patches are homogeneous (in structure and composition) areas of vegetation that differ from adjacent vegetation. Corridors are vegetation units that provide connectivity of similar patches through a different matrix or patch aggregation (Diaz and Apostol 1992).

The successional classifications of Steele, Arno, and Clausnitzer can be used as a framework for landscape element identification. The matrix, patches, and corridors would become dynamic ecosystem elements with predictable developmental pathways within a plant association framework. At the ecosystem scale of biodiversity, a successional classification provides compositional, structural, and functional knowledge for resource managers.

Landscape patterns in the inland Northwest have evolved in a heterogenous environment with a variety of disturbance regimes. Human activity has affected this natural landscape, often to a high degree. Com-

pleted studies of the region’s ecosystems should be supplemented with investigations of disturbance agents and regimes operating at different scales in the landscape to provide better understanding of ecosystem dynamics at the landscape scale.

To illustrate the use of successional classification in understanding ecosystem responses to both natural and human-induced disturbances, examples of the Blue Mountain grand fir series follow. A brief description of classification concepts precedes discussion of applications within an ecosystem framework.

The classification concepts presented by Steele (1984) have been applied in developing the successional classification for grand fir plant associations of southeastern Washington and northeastern Oregon (Johnson and Clausnitzer 1992, Johnson and Simon 1987). The plant associations are first separated into component layers of trees, shrubs, and herbs in recognition of the developmental independence of these layers. This independence is related to differential susceptibility to disturbance and differential rates of recovery in the tree overstory and shrub-herb understories. Within this successional framework, classification diagrams, keys, and association tables are displayed to represent the layer groups and layer types defined for each component layer.

Each layer group has a diagnostic seral indicator species present at 5 percent or greater abundance. For example, in the tree layer of the grand fir/Pacific yew/queencup beadlily plant association, five layer groups are defined. Each layer group is named for a seral indicator—western larch (LAOC), ponderosa pine (PIPO), Douglas-fir (PSME), Engelmann spruce (PIEN), or grand fir (ABGR). The species near the base of the classification diagram (fig. 21) have less successional amplitude than those near the top; that is, these species are found during the early stages only, but the climax species may be found during all stages. The western larch layer group is the earliest successional tree layer and includes stands with western larch at 5 percent or greater canopy coverage. Time is depicted as a vertical axis in the diagram.

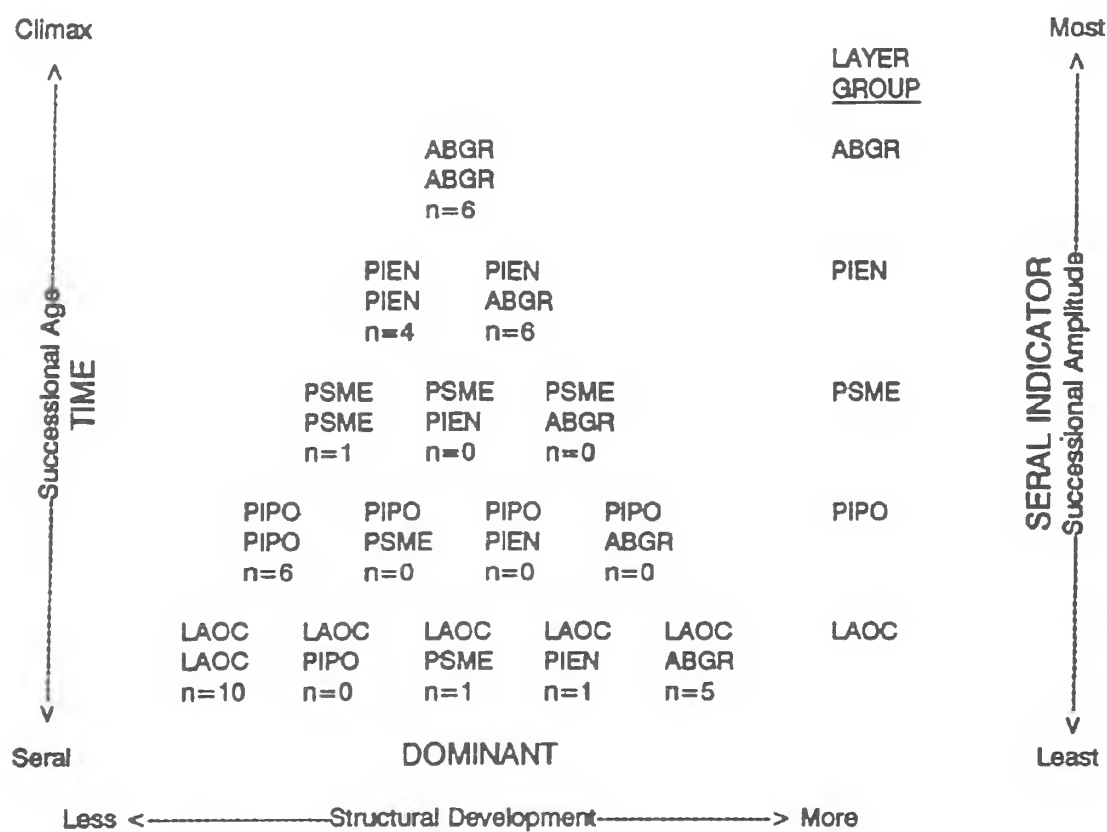


Figure 21. Successional classification of the tree layer in the grand fir/Pacific yew/queencup beadlily plant association.

Layer type is a classification unit in which a particular plant species dominates a portion of the layer group. The LAOC layer group has five layer types (fig. 21). These separate layer types depict stands dominated by western larch, ponderosa pine, Douglas-fir, Engelmann spruce, or grand fir; they represent structural and compositional development along the successional gradient within a layer group. The nomenclature for this unit combines the seral indicator species and the dominant species. For example, LAOC-ABGR would include all stands within this plant association in which western larch occurs at 5 percent or greater canopy coverage and grand fir dominates the tree layer.

Plant associations of the grand fir series are resilient and recover relatively quickly after light or moderate disturbance. High-intensity disturbances have slower recovery rates if combined with forest stand conditions of dense overstory and depauperate understory.

Two fire severities have been identified for the Blue Mountains of Oregon and Washington: underburning, and conflagration fire (Hall, unpublished). Where the mean fire return interval has been 10 years in forested stands, fire-resistant species dominate both the overstory and understory. Ponderosa pine is the dominant tree, and pinegrass or elk sedge is abundant in the understory. The conflagration fire has a return interval of 50 to 300 years. Lodgepole pine and western larch are dominant pioneer species in this regime. Understory shrubs and herbs are surviving members of the preburn plant community or they are early successional species reproducing from windblown seed or persistent seed stored in the soil.

Grand fir plant communities are uniquely affected by insect pests and pathogens. Susceptibility of individual stands to a particular pest depends on existing stand structure, composition, and environmental stress. Low populations of pests can cause the mortality of trees, either singly or in small groups. Outbreaks usually operate at another scale in the landscape and can result in tree mortality over large acreages. Historically, the mountain pine beetle, Douglas-fir tussock moth, and western spruce budworm have severely affected stands of lodgepole pine, grand fir, and Douglas-fir. These disturbance agents interact with forest stand composition and structure to retard, arrest, or accelerate vegetation development. For example, mountain pine beetle could either recycle a mature lodgepole pine community in the absence of other tree species or accelerate succession, if a vigorous seedling and sapling understory of grand fir were present in the stand.

Logging effects to forested plant communities are related to the season of disturbance by the specific activity (machine scarification, broadcast burning, pile and burn). The intermountain West has a truncated disturbance regime because logging has not been a historical disturbance factor in the same frequency as fire. Nonetheless, machine scarification has affected species establishment, survival, and growth in various ways. In grand fir plant associations, for example, huckleberry species are susceptible to this type of disturbance. More information is needed concerning community and species responses to these types of disturbance regimes.

Unlike the frequency of logging a site once every 120 years, the effects of grazing are related to the continuous or recurrent removal of biomass by ungulates. This disturbance regime should be studied in grand fir successional stages of the intermountain West. Vegetation changes within and outside of exclosures could compare effects of grazing on recovery rates, direction of vegetation development, productivity, and composition.

The tree layer of the grand fir/Pacific yew/queencup beadlelily plant association becomes increasingly susceptible to pests of grand fir as succession proceeds (fig. 21). The layer types show differential susceptibility (fig. 22). Elevated portions represent types susceptible to western spruce budworm outbreaks. For any individual pest, highly susceptible layer types could be identified and subsequent management designed to reduce negative effects.

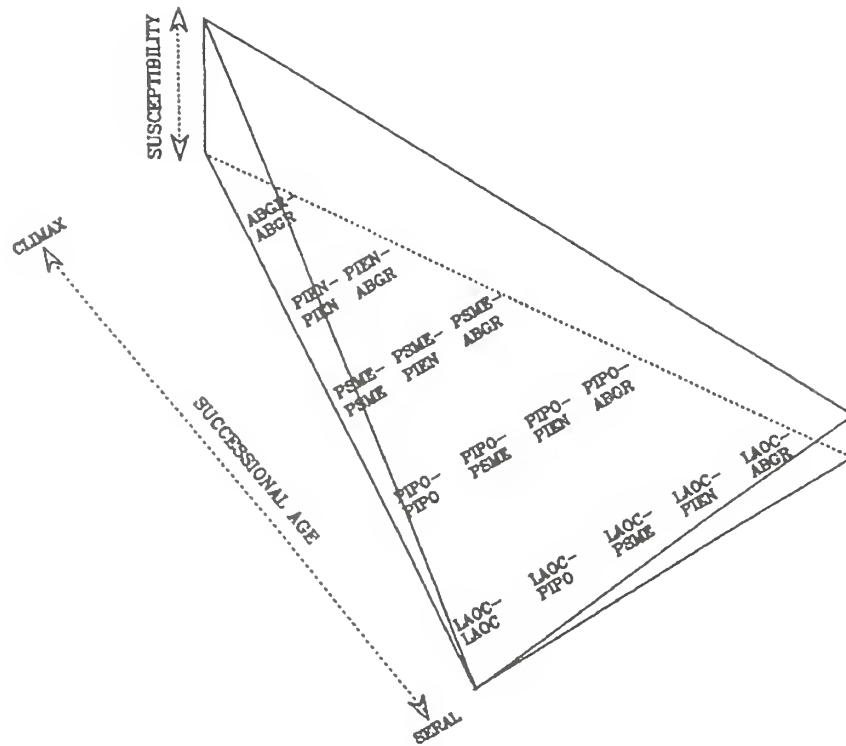


Figure 22. Western spruce budworm susceptibility plane for tree-layer types in the grand fir/Pacific yew/queencup beadlily plant association.

A successional trend of tree-leaf-area index in a grand fir plant association (fig. 23) illustrates a hypothesis of biotic and abiotic interactions about thresholds beyond which an ecosystem seemingly unravels. As succession proceeded, leaf-area index increased because both shade-tolerant and shade-intolerant trees established and grew. Periodic burning historically reduced leaf-area index, and it fluctuated within the range of natural variability (A and B). After fire suppression was initiated, leaf-area index increased to near the upper limit of natural variability. As climatic fluctuations led to lower soil moisture and subsequent water stress for trees, the upper limit for the range of natural variability shifted downward to reflect the lowered leaf area carrying capacity of the site. When leaf-area index exceeded the drought-induced threshold, tree mortality became significant because it was directly linked to the abiotic environment. But secondary agents (the western spruce budworm) may cause significant mortality through linkages to the abiotic and biotic environments. Budworm populations may interact directly with the warmer, drier environment in addition to indirect linkages with predator and parasite populations. Further, the budworm may interact with stressed host trees through reproductive structures (male and female cones), which are more abundant on stressed trees. These feeding sites may be more favorable to budworm populations (Mattson and others 1991). This community can be self-regulating, as long as structure and function are preserved, but exceeding threshold values may lead to a different trajectory of ecosystem recovery and development. However qualitative this conceptual model appears, it nevertheless displays abiotic and biotic interactions at the ecosystem scale important to resource management decisions.

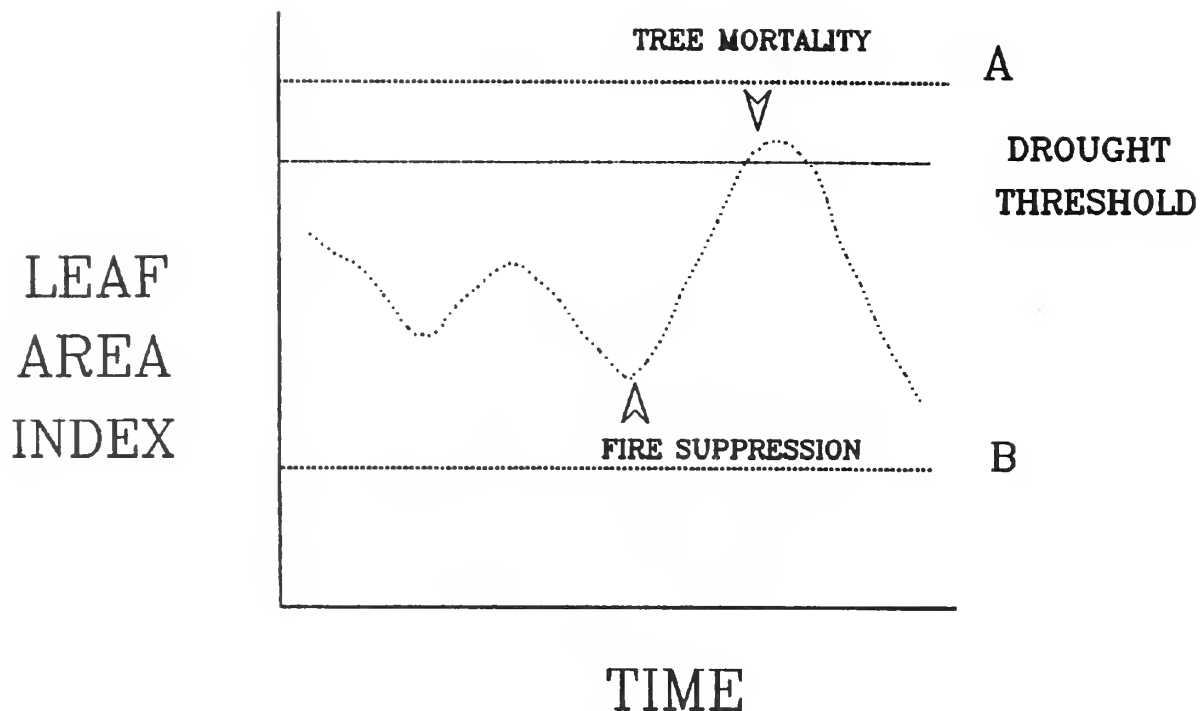


Figure 23. Leaf area index in a stressed ecosystem.

IDAHO FESCUE PLANT ASSOCIATIONS

The Relations Between Disturbances and Community Structure, Composition, and Distribution

The bunchgrass vegetation of the canyonlands in northeastern Oregon provide a mosaic on a contorted landscape that was sculpted over geologic time by mass-wasting after Pliocene flooding of the Snake River and its major tributaries (Baldwin 1964). The grassland soils are highly variable. Composition of bunchgrass community can vary dramatically based on soil depth below eroding rims or above buried basaltic flows. The aspect of bunchgrass sites also influences the kind of vegetation that can establish on them based on orientation to solar radiation and desiccating temperatures. The elevation of bunchgrass sites also determines temperature and moisture. Sites that can support the fescue plant association can occur between extremes of 1000 and 8000 ft elevation (Johnson and Simon 1987), but moisture availability is what allows fescue to persist at the lower elevations. Subsurface moisture emanating from the basaltic flows beneath the colluvium often determines whether moisture is sufficient to sustain fescue communities.

Of the three common bunchgrasses native to northeastern Oregon (Idaho fescue, bluebunch wheatgrass, and Sandberg's bluegrass), Idaho fescue requires more moisture and cooler temperatures (Daubenmire 1972). Therefore, where temperatures are warmer and soil moisture less, plant communities representing bluebunch wheatgrass plant associations can establish, but the more sensitive fescue communities cannot. Sandberg's bluegrass plant associations are found on shallow, dry, warm sites where soil depth and moisture are insufficient for the larger bunchgrasses.

The nine Idaho fescue plant associations described for northeastern Oregon (Johnson and Clausnitzer 1992, Johnson and Simon 1987) are distinguished by structure, composition and microhabitat; the associations reflect the environmental differences that influence their distribution across the varied relief of the canyons and ridges. At the most mesic end of the fescue continuum, Idaho fescue is associated with sedges. At the wetter end of the series are Idaho fescue-timber oatgrass (*Danthonia intermedia* Vasey)-sedge

and Idaho fescue-Hood's sedge plant associations. Four plant associations were described where prairie junegrass was associated. These Idaho fescue-prairie junegrass communities were intermediate between the moister meadow steppe associations and the drier fescue associations of the series. The prairie junegrass association with fescue is typified by substrates with low surface colluvium and rock. Finally, three plant associations represent the most xeric of the Idaho fescue series (and therefore the most allied to the bluebunch wheatgrass series). These are the Idaho fescue-bluebunch wheatgrass associations that are differentiated by three distinct environments at the warmer, drier end of the series.

Natural Disturbances as Modifying Events in Community Structure, Composition, and Distribution

As with all vegetation in eastside communities, Idaho fescue bunchgrass communities rely on periodic disturbance to rejuvenate and maintain vigor and vitality of the associated plant composition. The following events are ongoing and cyclic within bunchgrass communities of Idaho fescue plant associations:

Soil and slope movement—The majority of these communities are on steep colluvial slopes or on gentle ridgetops. The steep colluvial slopes are in constant movement; "stable," late-seral bunchgrass communities move 3 to 5 ft downslope over 15 to 20 years on 40 to 60 percent slopes (as defined by realignment of fixed transects across slopes from anchor positions at rim outcrops) (Johnson, unpub. data). On the gentle slopes and ridgetops, fescue communities contain 10 to 15 percent bare ground in late seral stages, with up to 50 percent rock and gravel on the surface. These bare patches are prone to frost heaving in the early spring after late winter saturation and freezing-thawing of the soil mantle.

Fire—Fire ignitions by late summer and early fall thunderstorms historically burned across these bunchgrass slopes with a haphazard, interfingering extension based on daily temperatures, wind velocity and the microrelief of the slope. Fire was certainly not uniform in its effects on the vegetation. Some areas burned intensively where standing biomass was dense and grass crowns were dry. In others, the burns were rapid and left the crowns of the grasses alive and ready for new tillers and sprouts with the onset of fall moisture. Of the three primary bunchgrasses, fescue is considered the most sensitive to fire. When the most mesic fescue associations burn intensely, associated forbs are promoted and succession regresses to earlier stages where forbs dominate until the reemergence of bunchgrass dominance in later successional stages. Natural fire regimes tended to burn with 10-year periodicity in open forest stands of the southern Blue Mountains (Hall 1976). The fire interval for bunchgrass vegetation was probably as frequent, with minor effects to the plant composition. When fires burn across the fescue-bearing landscapes today (after decades of fire exclusion) the effect of the burns is greater because of the buildup of dry, dense litter in the bases of the grasses.

Grazing—The modification of climax fescue communities has been greatest where the grazing animal has had easiest access to the range. In northeast Oregon canyonlands, fescue provides grazers with an early succulent plant, preferred over the taller bluebunch wheatgrass plant by elk, cattle, and sheep. Because soils are often wet in the spring, early grazing on fescue tends not only to consume the foliage, but also to dislodge plants from the ground. Perhaps the greatest detrimental grazing practice, which has decreased the vigor of bunchgrass, has been use by ungulates too early in the season and for too many seasons over time.

After continued pressure season after season, the stand of bunchgrass ultimately succumbs. As degradation continues in fescue communities, other plants tend to increase or invade—perennial forbs such as balsamroot (*Balsamorhiza sagittata* Pursh), lupine (Nutt.), field chickweed (*Cerastium arvense* L.); annual forbs such as deerhorn (*Clarkia pulchella* Pursh); and annual grasses such as cheatgrass (*Bromus tectorum* L.), rattlesnake brome (*B. brizaeformis* Fisch. & Mey.), and Japanese brome (*B. japonicus* Thunb.). Invading species are goatweed (*Hypericum perforatum* L.), Kentucky bluegrass, gumweed (*Grindelia* spp.), and tarweed (*Madia* spp.). Because grazing causes structural and compositional changes to the fescue community after overuse and abuse, the community dominated by bunchgrass in late-seral stages has forb-grass co-dominance in mid-seral stages and simpler communities dominated by either annual grasses or forbs in early seral stages.

Grazing, like fire, can be a stimulus to the bunchgrass plants and provide a natural, beneficial role to plant vitality and community stability. The key to maintaining and enhancing bunchgrass communities lies in timely grazing of the plants and the moderate use of the community. Studies have shown that early and repetitive grazing before seed set is injurious to the bunchgrass plant (Blaisdell and Pechanec 1949, Mueggler 1974, Pond 1960). Different classes of ungulates tend to graze the bunchgrass community preferentially, seeking different plant species within the community, which can benefit the vigor and vitality of the vegetation.

Management-Induced Disturbances of Idaho Fescue Grasslands

The climax fescue grasslands are a natural mosaic caused by topographic landform undulations, which in turn produce microclimates and promote differing grassland structures and compositions. Added to this diverse landscape are the superimposed modifications by past fires and by grazing pressures that have combined to form a variety of seral stages across the land. All of these effects are certainly not undesirable from an ecological perspective. Grasslands where lack of disturbance has resulted in late seral vegetation dominated by bunchgrasses to the virtual exclusion of other plants may provide the best forage for grass-eating ruminants. The greater diversity in plant species composition in mid-seral stages of fescue plant associations however, may provide the most balanced offering to all users of the grasslands (Thomas and Towell 1982). The early and very early seral stages of fescue grasslands that have increased from earlier use by land managers are the cause for concern to land managers today. Many sites capable of supporting Idaho fescue bunchgrass communities are so modified that they appear as bluebunch wheatgrass or Sandberg's bluegrass climax communities, or have been so thoroughly degraded that they contain no bunchgrass vegetation. Management for the next century must focus modern restorative techniques on these sites. Some of our grassland communities are so degraded that attempts at rehabilitation may be in vain. The principal problem beyond economics is the ability to protect restoration efforts from wild grazing animals long enough to establish the new community.

Introduction of Exotic Grasses

The grasslands of the northeastern Oregon area have had repeated rangeland improvement seedings in an attempt to rectify the damage of the past. The majority of these seedings have failed because highly preferred grass species were planted, and the grazers have sought them out immediately after the seed germinated. Also, some exotic species not appropriate for the environment were seeded. Restoring the grasslands should rely on planting native species, especially those mid- and early-seral species naturally promoted by disturbances. The forbs and grasses dominating in early- and mid-seral stages are the most likely to respond and be maintained on a degraded site. To assure availability of seed for native plant restorative work, local nurseries must be developed to produce the necessary seed from local populations.

Alien Invasion and Naturalization

The fescue grasslands of northeastern Oregon have diminished. The gentle benches and ridgetops have been severely affected by the plow and grazing animals. Alien plants have become firmly established, with no chance for natural succession to native bunchgrass vegetation without intervention by land managers. Examples of invasion can be found in cluster tarweed monocultures growing on deep, fertile ridgetop soils in the complete absence of native vegetation. Other ridgetop locations may look like thin-soil scablands. Onespike oatgrass, a climax codominant of scablands, can be found on deep soils of such fescue sites. Severe overgrazing has all but eliminated deep soil bunchgrasses to favor the shallow-rooted bunchgrasses (such as onespike oatgrass) as moisture retention diminishes.

Perhaps the most degraded fescue sites are found on the structural benches of the Snake River, Imnaha River, and Grande Ronde River canyons. These gentle benches (less than 20-percent slope) contain deep, clayey soils with abundant moisture provided by the contact between two prominent basaltic formations. Springs and seepages are numerous. Homesteaders, early ranchers, sheepherders, and wild ungulates all converged on these benches for the lush vegetation and ease of movement in an otherwise up-and-down world.

Today, the bunchgrasses are absent—or nearly so. Kentucky bluegrass has become the primary invasive species to dominate these benches, but red three-awn, annual bromes (cheatgrass, Japanese brome, rattlesnake brome), and goatweed all may be found in large patches throughout these benchlands (Johnson and Simon 1987).

The presettlement vegetation cannot be brought back on these sites. Attempts to do so would require the impossible task of ridding the community of all naturalized aliens. Perhaps the most notorious of these is cheatgrass. Virtually all plant communities in the canyonlands contain this species, along with one or two other naturalized aliens. The task of rebuilding biological diversity through diversification of the plant community with earlier seral forbs and bunchgrasses is a goal to pursue.

Sustaining Eastside Vegetation

The eastside landscape has been modified by disturbing agents and activities. Some of these modifications are natural to the ecosystems and are part of the process of ecosystem maintenance. Other modifications have been induced by human activities on the landscape, and Euro-Americans have had the greatest effect over the past century. The questions that land managers ask about maintaining or enhancing ecosystems is, “What can we do without surpassing the capacity of the sites to rebound from highly disturbed communities toward natural successional pathways?” And, at what point has a particular site, or complex of sites, been so severely affected as to be unable to respond to enhancing activities?

Variables that influence thresholds also determine the capacity of a site to develop a particular kind of plant community. Soil fertility, moisture, temperature variation, and presence of disseminules are the key factors influencing plant community development. As a degrading modification occurs on a site, any one or all of these factors may be negatively affected. For example, continued overgrazing of a late-seral bunchgrass community will increase the percentage of bare ground exposed to erosive wind and water. Grazing too early in the season may compact the soil through trampling. Moisture availability may be curtailed earlier than normal in the growing season with removal of standing herbage and subsequent loss of shading by growing foliage and litter (both of which have been removed by overuse). The lack of standing foliage and the loss of litter also cause the microsite to heat up and be too warm for plants that require cooler, moister conditions. Likewise, lichen and mosses between the rocks, gravel, and plants on the soil surface, are affected by the surficial disturbance by grazing animals. As the degree of disturbance increases, the microclimate of the ground surface changes. Temperatures become lethal to mosses and lichens on the site. The severe effects of overgrazing on bunchgrass foliage results in the inability of the plants to produce viable seed. And the plants are too weakened to send out new tillers. The relation of moisture and temperature has changed so that the plant species is no longer sustainable on the site.

This scenario has occurred not only in bunchgrass communities, but also on sites supporting shrublands, forests, and wetlands. These sites are incapable of response, even when the degrading activity stops, and a “disclimax” is created by the degrading activities. To regain a resemblance of the original vegetation on the site, managers must intervene—at great expense in time, energy, and dollars.

The key to restoring these ecosystems is to understand the interactions of the component parts. To understand ecosystems requires the talents and wisdom of trained professionals, experienced technicians, and leadership of an interdisciplinary team of ecologists and other specialists. This team must understand that information is insufficient to make decisions correctly on behalf of all ecosystem components. They must also understand those processes the ecosystem requires to maintain itself, in light of the modifications being planned. Decisions must be conservative to avoid the risk of error that would take the system beyond its sustainable threshold.

Passive management is not the best choice after the long tenure of human management of the land. To improve degraded ecosystems and landscapes requires active use of tools and techniques still being developed. The key is to shift from functionalism to multifunctional projects performed on a large scale. Degraded landscapes and vegetation on the eastside cannot be improved without planning, conducting, and monitoring restoration projects at a landscape scale.

The State of the Landscape on the Eastside

After more than a century of active land management, the various ecosystems and included plant communities of the intermountain Pacific Northwest are in need of nurturing assistance from the human population. In comparison with other sectors of the United States and other countries in the World, this part of the planet is in relatively good shape. Entire provinces of the region have not been placed under intensive agriculture, nor have large segments of the forested landscape been converted to subsistence agricultural pursuits. Great numbers of plant and animal species have not been displaced to the point of extinction. And the human population has not yet overwhelmed the region so as to make quality of life unacceptable to the majority of its occupants.

This “sanctuary” will surely be found, however, and the pressures exerted by an expanding society will cause our vegetation, natural resources, landscapes, and ecosystems to be overexploited and forever modified. The time to act is now. The way to act is to focus on the landscape; to emulate the disturbances that have created and shaped its plant communities; to initiate projects on a large scale that use modifying events to enhance the combined plant communities of the included ecosystems; and to cease those destructive activities that do not replace elements required by the ecosystem.

CONCLUSIONS

People observe succession in a life span that is but a “few frames in a continuous movie.” people have envisioned idealized stable cycles and classified vegetation into artificial units based on their perceptions of how plants interact competitively over time. They have imagined the forest and steppe primeval as one of pristine vegetation. Paleo-vegetation studies have shown that vegetation has changed dramatically in composition and extent in the intermountain Pacific Northwest over the past 20,000 years. The forest and steppe plants have responded rapidly to environmental disturbance. Change is continual, change is unpredictable, and climatic shifts will continue to exert a large influence on the steppe-forest interface in the future.

Successional pathways depict the probable course of community development within a framework of defined community types for a disturbance regime. Altered abiotic and biotic interactions may lead to different responses by individual plant species and the identification of different successional pathways. Knowledge of plant succession is the foundation of a sound vegetation management program where the primary goal is to retard, arrest, or accelerate the natural forces of vegetation change. Many investigations have studied community responses to a single disturbance; now the variations of community responses to different disturbance regimes must be studied.

Both natural and human disturbances have long-term influence on the appearance and species compositions of eastside vegetation. The long-term consequences of natural disturbances are, for the most part, enhancing to biological diversity. The natural disturbances that resulted in the current vegetation need to be reintroduced. The scale of the modifying events and activities needs to shift from species and stand to the landscape scale. Activities that do not replace elements and processes needed for maintaining and enhancing the ecosystems must be curtailed. After more than a century of active land tenure and management by Euro-Americans, the various ecosystems of the eastside are in need of nurturing.

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Biotic and Abiotic Processes in
Eastside Ecosystems:
The Effects of Management on Soil Properties,
Processes, and Productivity

by

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ABSTRACT

Productivity of forest and range land soils is based on a combination of diverse physical, chemical and biological properties. In ecosystems characteristic of eastside regions of Oregon and Washington, the productive zone is usually in the upper 1 or 2 m. Not only are the biological processes that drive both soil productivity and root development concentrated in limited organic horizons, but also they have evolved historically in a natural system that includes mostly modest surface disturbance. Typical disturbances include erosional, seismic, or tip-over events, and modest surface heating by periodic wildfire. This combination of properties and processes produces soils with an extremely wide range of productivity potential, but productivity can be highly sensitive to disturbances from heavy machinery or fire, when fuel accumulations are well beyond historical norms. Limited moisture-holding capacity and nitrogen storage often impose a need for carefully balancing developing vegetation with available soil resources.

INTRODUCTION

Inland, the Pacific Northwest has a diverse geologic history, varying microclimates within diverse macroclimates, and a record of extensive natural and human-caused disturbances. The resulting soils and their associated vegetation are on landscapes that are spatially complex, and differ in appearance, function, and response to management actions. Depending on their suite of properties, soils range from very sensitive to relatively tolerant of disturbance. Thus, management prescriptions must be site specific.

Soils develop over extended periods (decades to centuries), depending on the characteristics of landform and ecosystem. Because physical site disturbances are rare, eastside soils are the result of the chemical and physical properties of parent materials, such as erosional and glacial deposits, gradually decomposing bedrock, overlaying deposits of volcanic ash and pumice, and windblown soil from adjacent regions (loess). Chemical weathering of rock requires many centuries. The principal volcanic ash and pumice deposit on eastside soils dates from the eruption of Mount Mazama, about 6600 years ago. Loess deposition has been cumulative and required many thousands of years. However, the surface 30 cm (perhaps most important from the standpoint of either short or long-term productivity) are strongly affected by accumulating deposits of organic materials input by vegetation, mostly over time spans from a few decades to several hundred years (Harvey and others 1987).

Eastside soils are typified by specific forest floor horizons, consisting, at the surface, of a modest amount of litter (usually 3-5 cm) underlain by humus (sometimes less than one cm thick); then a mineral horizon enriched by organic matter from overlying materials (about 5-40 cm) and, finally, a mineral base that may or may not contain organic material, ash, or loess deposits that improve general fertility and water storage capacity. Interspersed within this mix are deposits of old decayed wood (150-550 years old) that can be deep (5-20 cm) and located throughout the shallow soil profile. About 5 to 10 percent or more of the top 30 cm of these soils can consist of woody materials (Harvey and others 1987; Meurisse and others 1991; Page-Dumroese and others 1991, 1993).

Soil fertility, of course, is critical to productivity. Eastside ecosystems are climatically limited (low water input during the growing season), and soils are mostly young with highly variable fertility. Water and nutrients tend to accumulate and cycle in surface layers, primarily organics, volcanics, and loess, when present. Most critical processes are at soil depths ranging from 5 to 40 or more cm. Concentration of these processes at the soil surface makes them potentially sensitive to disruption and highly variable from site to site (Jurgensen and others 1990).

Some eastside forest sites were beneath ice caps only 10,000 years ago. Existing vegetation systems often have developed only recently and are largely typical of a changing postglacial climate. Where ash, loess, or

other fire deposits are present, however, water and nutrient storage can lead to vegetation types typical of a moister climate, and substantial buffering of climate or site perturbations is likely. Where such soil deposits do not exist or are limited, soil productive capacities may be tightly linked to organic horizons and little buffering is possible.

Root morphology and the ability of terrestrial vegetation (especially trees) to “mine” variable soils is not well understood. For eastside ecosystems, feeder root production seems concentrated within the most fertile shallow soil horizons; this concentration contributes substantially to the deposition and cycling of nutrients and carbon in those horizons (Keyes and Grier 1981; Vogt and others 1987). Whether tree root systems are adapting to deep sources of water, nutrients, or both, is unknown. Large root-to-top ratios are typical of trees growing in dry and/or infertile environments (Vogt and others 1987), so energy requirements for exploiting resources in short supply are higher than where resources are abundant. How much can trees adapt to changing environments across time and space? Information on above/below-ground interactions of trees and stands across environmental and temporal gradients will eventually be required to fully understand and interpret soil/vegetation interactions that govern site productivity processes and their responses to change.

Eastside ecosystems are highly valuable in their ability to balance long-term soil and rooting processes with aboveground productivity. Consequently, wide variations in site productivity, tree mortality, vegetation response to soil disturbance, and soil stability are characteristic. Based on combinations of site, soil, vegetation, and management history, however, these responses should be predictable. The following information provides both scientific tools and perspectives for making such predictions.

THE PHYSICAL AND CHEMICAL NATURE OF EASTSIDE SOILS

Soil Origin

East of the Cascades Range, volcanic ash and pumice depositions are a major influence on many soils and associated vegetation. The most encompassing deposition occurred about 6600 years ago from the eruption of Mount Mazama, which produced Crater Lake, in Oregon. That eruption blanketed areas of eastern Oregon and Washington and beyond. An earlier eruption of lesser influence came from Glacier Peak in the northern Washington Cascades Range about 12,000 years ago (Fryxell 1965). The eruption of Mount St. Helens, including the 1980 eruption, have had comparatively little effect on forests east of the Cascades Range.

Estimated minimum fallout areas for Mount Mazama was 900,000 km² and for Glacier Peak, 260,000 km². The less expansive Glacier Peak deposition spread east-southeast in a fairly narrow belt from the source; the Mount Mazama fallout was broadly north and east, with some southerly coverage. In both eruptions, the deposition of thick, coarse pumice now found near the volcanoes rapidly thins and becomes increasingly fine with greater distance from the source. The Mazama ash is most evident (Fryxell 1965) and deposits up to 1 m thick are common as far away as northeastern Oregon and northeastern Washington. The original deposition has been altered at many locations by wind and water erosion. Also, road building, livestock grazing, logging, and other human activities have had some local effects on deposits.

Vegetation and Associated Soil Properties

Conditions created by changes in climate and volcanic ash deposition have affected the abundance, growth, and kinds of plants and thereby altered the distribution patterns of vegetation on landscapes. For example, grassland, juniper (*Juniperus occidentalis* Hook.), and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) were much more widely distributed than the more productive mixed conifer and spruce-fir types in the warmer, drier period before ash-fall, according to pollen counts from local bogs (Mehring 1985). Ash deposited on grasslands eroded away, but much of the ash deposited on forested sites remained and

resulted in soils with high water-holding capacities. These ash soils and the colder, wetter climate of today support large acreages of mixed conifer and spruce-fir forests.

Four major forest types represent 93 percent of the forested landscapes and occupy about 21.4 million acres east of the Cascades in Oregon and Washington (Reid 1947). These types are ponderosa pine, mixed conifer, lodgepole pine (*P. contorta* Dougl. ex Loud.), and spruce fir. The mixed conifer type consists of various mixtures of interior Douglas-fir (*Pseudotsuga menziesii* var *glauca* (Beissn; Franco), white fir (*Abies concolor* (Gord. & Glend.) Lindl.) or grand fir (*A. grandis* (Dougl. ex D. Don) Lindl.), western white pine (*Pinus monticola* Dougl. ex D. Don), western larch (*Larix occidentalis* Nutt.), and western redcedar (*Thuja plicata* Donn ex D. Don). In the southern Oregon Cascades, the spruce fir type consists primarily of Shasta red fir (*A. magnifica* Murr. var. *shastensis* Lemm.) and certain associated species, but elsewhere the type consists of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*A. lasiocarpa* (Hook.) Nutt.).

Forest Types and Associated Soil Properties

Soil moisture and soil temperature regimes are paramount variables affecting the distribution, species mix, and productivity of inland Northwest forests. Four different soil moisture regimes combine with three different soil temperature regimes (table 1) to broadly influence the kind and character of forest vegetation including forest types (table 2). Descriptions of these forest types, which follows, further indicate the differing character of eastside forests and associated soils.

Table 1—Soil moisture and temperature¹ regimes in western-montane forests

Soil moisture regimes		Soil temperature regimes	
Name	Description	Name	Description
Semi-arid (aridic)	Soil moisture control section is dry more than half the time that the soil temperature is above 41° F. Never moist for 90 consecutive days where soil temperature is above 47° F.	Cool (mesic)	The mean annual soil temperature is 8° C (47° F) or higher, but lower than 15° C (59° F). The difference between mean summer and winter temperature is more than 5° C (9 F).
Moderately dry (xeric)	The soil moisture control section is dry for 45 days or more consecutive days within the 4 months after the summer solstice. Typified in Mediterranean climates where winters are moist and cool and summers are warm and dry.	Moderately cold (frigid)	The mean annual soil temperature is lower than 8° C (47° F) and the mean winter and summer soil temperature is more than 5° C (9° F).
Moist (ustic)	Soil moisture control section is dry for 90 or more cumulative days but is moist in some part for more than 180 cumulative days. Soil moisture is limited, but available when conditions are suited for plant growth.	Cold (cryic)	Soils have a mean annual temperature higher than 0° C (32° F) but lower than 8° C (47° F) with an O horizon.
Moderately wet to wet (udic)	Soil moisture control section is not dry for as long as 90 days (cumulative) and not dry for as long as 45 consecutive days in the 4 months after the summer solstice. Stored soil moisture plus rainfall > ET amount.		

¹ Measured at 50-cm depth

Table 2—Moisture and temperature regimes of eastern Oregon and Washington and their associated major forest types

Semi-arid to moderately dry, cool to cold	Ponderosa pine
Moderately dry to moderately wet, moderately cold to cold	Ponderosa pine (interior Douglas-fir, larch), mixed conifer (grand or white fir)
Moist to moderately wet, cool to cold	Mixed conifer (western white pine-western redcedar), lodgepole pine, spruce-fir

Ponderosa pine type—Ponderosa pine forests occupy the warmest, driest forested sites of the inland Northwest. Available soil moisture is closely related to pine distribution and productivity. In the central Oregon pumice plateau, however, frost pockets limit distribution, and ponderosa pine is often replaced by lodgepole pine (Cochran 1973, 1975). Sugar pine (*Pinus lambertiana* Dougl.) commonly occurs on volcanic cones and buttes. Mean annual precipitation ranges from 41 to 89 cm; precipitation generally falls during autumn and winter when evapotranspiration is low. Mean annual temperatures range from 7 to 18°C. The soils are usually dry at depths of 10 to 61 cm for 60 or more consecutive days during summer and autumn (Daubenmire and Daubenmire 1968, Donaldson and DeFrancesco 1982, Hall 1973).

Ponderosa pine forests generally grow on three broad but distinct groups of soils (Dyrness and Youngberg 1966). In Oregon, probably the most prominent and contiguous of these soils are those from air-laid pumice and ash. These cinder- and pumice-soils often overlie older, loamy soils buried at depths of about 30 to more than 150 cm. These soils are coarse, but store relatively high amounts of readily available soil moisture (Carlson 1979, Dyrness and Youngberg 1966, Larsen 1976). Soil organic matter is concentrated within 15 to 25 cm of the surface and declines rapidly with depth. Although these soils are relatively resilient, assurance of site productivity potential requires that the nutrient regime be maintained by conserving organic matter and minimizing soil displacement.

The second most prominent group of ponderosa pine soils are those that are moderately deep and dark colored, fine, and fine-loamy; these soils are derived from basalts, andesites, and clayey sediments. When wet these soils are easily puddled and compacted, but when dry they have relatively high strength. On slopes greater than 30 percent, surface erosion is especially significant when vegetation is removed (Carlson 1974, Paulson 1977, Wenzel 1979).

The least prominent group of ponderosa pine soils are those that are coarse, loamy, and shallow to deep; these soils are derived from rhyolite, andesite, granitics, glacial till, and outwash. They usually have low organic matter content and low plant-available, water-holding capacity (less than 8 to 10 cm). For this group, soil displacement and erosion represent potential hazards to long-term productivity, particularly on slopes greater than 30 percent, and organic matter, surface soil nutrients, and moisture conservation are critical for maintaining long-term productivity of ponderosa pine (Harvey and others 1989b, Powers and others 1989).

Mixed conifer type—Mixed conifer forests occupy a wide range of soil conditions. At the lowest elevations, soils are relatively warm and dry; at the highest elevations, they are cold and wet. Species composition is diverse. Species composition and stand productivity are governed by available soil moisture, nutrient supply, and temperature (Daubenmire and Daubenmire 1968, Hall 1973).

The dominant feature of the interior mixed-conifer sites is the presence of various amounts of surface-deposited pumice and volcanic ash. Deposition thickness ranges from about 15 to more than 76 cm. This layer is generally underlain by older, buried soils of various origins with textures from sandy loams to clays. Some buried soils contain gravel and stone. Total soil depth ranges from about 0.3 to more than 1.5 m (Donaldson and DeFrancesco 1982).

Temperature is a major factor affecting productivity and species composition in this forest type, and two distinct temperature-related soil groups can be described. The larger and more productive—the frigid regime—has mean annual soil temperatures of about 6 to 8 °C and mean summer soil temperatures of 16 to 17 °C. Elevation ranges from 600 to 1672 m. Mean annual precipitation ranges from 46 to 127 cm. For most sites the soils are dry at depths of 20 to 61 cm for 60 consecutive days or more. A few localized areas are dry for less than 45 consecutive days and usually have western redcedar/clintonia or western hemlock/clintonia plant associations. The range of vegetation—from low to high elevations, as well as from dry to wet soil conditions—is Douglas-fir, western larch, lodgepole pine, grand fir, white fir, western white pine, western redcedar, and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Climax species are: Douglas-fir on the driest sites; grand fir and white fir on moister sites; and western redcedar on the wettest sites. This soil temperature group supports the most productive forests within the ecosystem. Productivity for this frigid regime soil commonly ranges from 5.9 to 8.0 m³ha⁻¹yr⁻¹ (Donaldson and DeFrancesco 1982, Hall 1973, Johnson and Simon 1987, Volland 1985). Root disease problems are particularly common in these types (McDonald and others 1987).

The other major temperature-related soil group—the cryic regime—has mean annual soil temperatures of about 3 to 7 °C and mean summer soil temperatures of less than 16 °C. Elevation ranges from 1064 to 1800 m. Mean annual precipitation ranges from 51 to 127 cm. Although some of the soils are dry for 45 to 60 consecutive days during the summer, many localized areas are dry for less than 45 days. Predominantly, vegetation includes: white fir, grand fir, Douglas-fir, lodgepole pine, Engelmann spruce, and subalpine fir. Western redcedar, western hemlock, western larch, and western white pine are minor components. Site productivity potentials generally range from 3.5 to 5.9 m³ha⁻¹yr⁻¹, except on the driest, coldest sites, where they can be less (Donaldson and DeFrancesco 1982, Hall 1973, Johnson and Simon 1987, Volland 1985). Root diseases are also common in these forests (McDonald and others 1987).

Because so many of the soils in the mixed conifer forests are derived from or are strongly influenced by volcanic ash, they generally have relatively high water-holding capacities. Plant-available water capacities of 25 to 30 cm are common. Natural soil bulk densities average about 0.6 g/cm³ but can vary, depending on location and management effects. These low densities provide for rapid infiltration, high water-storage capacity, and good aeration (Donaldson and DeFrancesco 1982, Volland 1985). Maintaining long-term productivity requires protection from excessive compaction and displacement of the surface soil (ash and organic matter components). These frigid and cryic soil regimes are among the most fertile of the inland Pacific Northwest forests, but to maintain productivity levels, management of nutrient reserves and organic matter is critical (Geist and Strickler 1978, Harvey and others 1987, Sachs and Sollins 1986).

Lodgepole pine type—Lodgepole pine forests of the inland Pacific Northwest usually occupy relatively moist, cool to cold sites where mean annual precipitation ranges from 50 to 127 cm and mean annual air temperature from 4 to 16 °C. Mean summer soil temperatures range from 7 to 16 °C. Lodgepole pine forests in much of Oregon and Washington grow predominantly on soils derived from silt loam volcanic ash and loamy sands from pumice and ash (medial and cindery Typic Vitrandepts and Cryandepts). In the pumice plateau of central Oregon, these forests are usually in nearly flat basins that may have water tables at depths of 30 cm or more. These soils generally have high amounts of readily available water storage, low bulk densities, and moderate to low fertility. Most nutrients are concentrated within 15 cm of the surface (Cochran 1971, 1985; Geist and Strickler 1978; Youngberg and Dyrness 1959).

Spruce-fir type—Most of the eastside spruce-fir forests are similar to Rocky Mountain subalpine fir-Engelmann spruce forests, but are not as widespread. This type occurs in the coolest and wettest forested zones. Mean annual soil temperatures are about 3 to 7 °C. These forests are mostly at elevations from 1612 to 2260 m and are often in frost pockets and other habitats, such as glaciated valley bottoms characterized by cold air accumulation. Common soil parent materials are ash plus colluvium, however, ash plus alluvium and basalt materials also occur. Soils are more acid than in the lower forested zones, with pH values typically 4.5 to 4.9. Well-developed but relatively thin organic layers occur. Major tree species in this type are subalpine fir, Engelmann spruce, and lodgepole pine. For this forest type, some locations may also include Douglas-fir, grand fir, western larch, and western white pine (Franklin and Dyrness 1988, Johnson and Simon 1987).

Along the east slopes of the southern Oregon Cascades, about 43° north latitude, the complement to the spruce fir type is the Shasta red fir zone. Common associates are white fir, western white pine, lodgepole pine, and mountain hemlock (*T. mertensiana* (Bong.) Carr.). In specialized habitats, Douglas-fir, ponderosa pine, incense cedar (*Libocedrus decurrens* Torr.), Engelmann spruce, Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) and subalpine fir may also be present. Without disturbance, these soils usually have well-developed organic layers (Franklin and Dyrness 1988). Usually coarse and stony, these soils are developing in glacial outwash and volcanic ash mixtures. Usually, fertility is relatively low.

Soil Properties

Soils act as heat sinks and sources and serve as the repository of mineral nutrients and water. Soils also provide an anchoring medium for the roots of higher plants, and house a complex, dynamic microbial population. This microbial population decomposes organic material deposited on and within the soil profile and drives the nutrient cycling processes within the ecosystems.

Chemical soil properties—Soil organic matter content is one of the most important attributes of any soil and enhances both chemical and physical properties. Organic matter contains most of the nitrogen (N), phosphorus (P), and sulfur (S) that will become available to higher plants, and these nutrients are commonly deficient. Soil organic matter is usually concentrated near the soil surface. Percentages decline rapidly with soil depth, as shown by examples of representative soils from broad vegetation groups and parent material sources (tables 3 and 4). Concentrations of nutrient bases—extractable potassium (K), calcium (Ca), and magnesium (Mg)—in soils also differ when grouped according to combinations of parent rock and associated forest types. In northeastern Oregon, the concentrations of bases are notably higher under ponderosa pine, which is strongly associated with basalt and andesite parent rock. Soils of volcanic ash origin are commonly lower in base concentrations, regardless of associated forest type (table 4). Concentrations often increase at lower depths in the soil as clay content increases (Geist and Strickler 1978). Soils of the central Oregon pumice plateau that support ponderosa and lodgepole pines are even lower in extractable bases than the ash soils of northeastern Oregon, apparently because of less weathering in the pumice (Geist and Cochran 1991, Youngberg and Dyrness 1964). Because chemical properties are highly variable in the inland Pacific Northwest, site specific conditions must be assessed in making management decisions.

Table 3—Mineral soil organic carbon in representative soils of eastern Washington and Oregon

Moisture-temperature Regime	Forest types	A Horizon		Total Solum or 90 cm depth
		(Organic carbon)	(% of total)	mg
Moderately dry- Moderately cold (Xeric-Frigid)	Ponderosa pine	30	41	74
	Grand fir—Douglas-fir	9	10	94
Moderately dry- cold (Xeric-Cryic)	Ponderosa pine	20-22	55-64	37-38
Moderately wet- Moderately cold (Udic-Frigid)	Grand fir—Engelmann spruce	20	38	53
Moderately wet- cold Andisols (Udic-Cryic)	Engelmann spruce— subalpine fir	44	34	128

Table 4—Total nitrogen (N) available phosphorus (P), and extractable cations at 4 different depths for some northeastern Oregon soils in the spruce-fir, mixed conifer, ponderosa pine, and lodgepole pine types

Spruce fir				Mixed conifer		
Soil depth	N	Available P	Extractable cations	N	Available P	Extractable cations
cm	%	ppm	meq/100g	%	ppm	meq/100g
0-15	0.22	45	4.4	0.1	63	11.2
15-30	0.16	21	3.0	0.06	36	9.3
30-60	0.09	17	2.7	0.04	22	11.2
60-90	0.06	26	8.8	0.03	12	14.8
Ponderosa pine				Lodgepole pine		
0-15	0.11	44	14.8	0.09	51	6.0
15-30	0.07	31	14.2	0.05	31	6.2
30-60	0.04	24	16.7	0.03	17	9.5
60-90	0.03	17	24.3	0.03	12	15.4

Physical soil properties—Bulk density (dry weight per unit volume), porosity, pore-size distribution, texture, hydrologic conductivity, soil depth, and rock content are all related to water-holding capacity and availability to plants. When combined with site attributes like elevation, slope, and aspect, these properties greatly influence the amount and kind of vegetation on a landscape, particularly in regions with very low summer precipitation like the Pacific Northwest. Soils forming in ash and pumice have very high porosities and high water-storage capacities (table 5). Soils of basalt origin contrast markedly with soil of ash origin (table 6). The water retention difference between 0.1 and 15.0 bars of water stress is used to approximate plant-available water capacity.

A physical-chemical binding between organic matter and mineral soil particles also contributes to the development of soil structural characteristics. Increased organic matter results in greater macropore space and pore continuity within the soil. These factors contribute markedly to the ability of soil to store water and the rate of water movement into and through the soil. High water intake reduces vulnerability to overland erosion by water. Organic matter interaction with soil particles also increases the ability of soil to store water for plant growth.

Soils with internal layers of unweathered pumice have high porosities and store large amounts of water. The pumice particles are bridged, however, greatly reducing the degree of root proliferation. Consequently, much of the water stored in such layers is not reachable for plant growth (Cochran 1971).

The most water-limited landscapes of the eastside are those supporting grasslands, shrubland, and juniper woodland. Where the large array of interacting factors affecting water availability result in more favorable conditions, stress-tolerant ponderosa pine is found. As water availability improves, the mixed conifer type occurs first, then the lodgepole pine type, and finally, the spruce-fir type.

Primarily because of their high porosity, soils dominated by pumice and ash have low thermal conductivities, low heat capacities by volume, low thermal diffusivities, and low thermal contact coefficients. These thermal properties—when combined with the usually dry air mass, frequency of clear skies, and the high elevations in eastern Washington and Oregon—result in a high frequency of radiation frosts during the growing season, particularly in flats and depressions. Radiation frost is an important

Table 5— Generalized comparisons of physical properties for surface layers of ash-, pumice-, and basalt-derived soils, 0 to 30-cm depth (adapted from Geist and Strickler 1978, Meurisse and others 1991, Youngberg and Dyrness 1964).

Property	Ash, eastern Oregon	Pumice, central Oregon	Basalt, eastern Oregon	Ash, eastern Washington	Sandstone, eastern Washington
Bulk density mg/m ³	0.7	0.6	0.9	0.6	1.6
Porosity, % by volume	73	77	65	77	40
Clay, % by weight	10	8	20	3	10
Coarse fragments, % by volume	4	25	30	0	0
Available water, % by volume	30	30	13	26	14

factor governing the distribution pattern of lodgepole pine and ponderosa pine on the pumice-mantled topography of central Oregon. These soils are also particularly susceptible to frost heaving, which can either kill plant seedlings or retard their growth and lengthen the time necessary for reestablishment of vegetation after disturbances (Cochran 1973, 1975). Physical soil properties, like chemical soil properties, are highly variable and require consideration of site specific conditions.

Soil surface erosion—Because the soils of the inland Pacific Northwest are, in themselves, variable and are on variable landscapes, their potential for surface erosion is also highly variable. As a general rule, however, the high infiltration rates in most soils of this region usually mean that erosion hazard is relatively low on slopes of less than 30 percent. On steeper slopes, surface erosion hazard can increase measurably if the soils are barren. Also, even on gentle slopes, when water is concentrated from roads or ditches, the soils from ash and pumice are subject to gullyng because of their low density and cohesion.

Soil ravel and mass wasting—Soils on the east slope of the Cascades, especially in central Washington, are subject to mass wasting, which includes slump-earth flow and debris torrent failures. Slump earth-flow failures are mostly in the fine-textured soils, and debris torrent failures occur in weakly cohesive ash, pumice, and other materials that often overlie compacted tills (Helvey and others 1985). Dry ravel can be

Table 6—Soil water held between 0.1 and 1 bars (low soil-water stress), and 1 to 15 bars (medium to high water stress) in 2 example parent materials

Soil depth cm		Low 0.1 to 1 bars	Medium 1 to 15 bars
Percentage of soil water by volume			
Ash	0-15	26.1	4.4
	15-30	26.9	4.9
	30-60	24.7	5.7
	60-90	11.8	6.2
Basalt	0-15	11.7	5.1
	15-30	11.2	5.2
	30-60	9.9	5.0

significant on slopes greater than 40 percent in pumiceous, cindery, and ashy soils (Helvey and others 1985). These conditions are confined to specific areas in the central Oregon Plateau and eastern portions of the central Washington Cascades. Where these conditions occur, even minimal disturbances can lead to regeneration difficulties.

THE STATUS OF ORGANIC MATTER IN EASTSIDE SOILS

Soil organic matter is an important factor for the continued productivity of eastern Oregon and Washington forests. It has an integral and sometimes critical role in soil water availability, nutrient cycling, seedling establishment, growth, and erosion control. Additions, alterations, and reductions of this organic resource have a great influence on both biotic and abiotic properties of any given site (Harvey and others 1987). Soil organic matter has a variety of physical and chemical characteristics that greatly affect soil physical and biological properties, plant nutrition, and the spread of insects and diseases (Larsen and others 1980).

In unmanaged forests of this region, organic matter decomposition is frequently slow, leading to surface organic matter accumulations. Such accumulated litter and woody residues represent potential fuel for wildfire, an important force in the development of all inland Pacific Northwest forests (Habeck and Mutch 1973). If fuel accumulation is excessive, the resulting fire may be extremely hot and soil organic matter losses large. Many forests in eastern Oregon and Washington have high fuel loadings because of extensive overcrowding, stand stagnation, and tree mortality from insect and disease attack. The danger of catastrophic wildfire is increasing on these sites. If ground fuels are reduced by a combination of forest management activities, the potential for severe fire damage is lowered. These same management activities, however, can also have negative effects on soil organic contents. The interactive roles of wildfire, forest management practices, and organic matter decay are critical for forest productivity in this region (Harvey and others 1979).

Nature and Distribution of Soil Organic Matter

The type and distribution of soil organic matter in eastside forests varies widely and depends on stand age, stand location, tree species, and fire history. Old-growth stands (150 to 250 years old) are useful references for the extent of organic matter accumulation in natural, unmanaged forests. They represent a long-term interaction between forest, climate, and soil processes and are indicative of a balance between site productivity and stability. As such, old-growth stands provide a model with which to estimate the effect of management activities on soil organic content and site productivity. The majority of soil organic matter in these old-growth forests is found in surface organic layers (forest floor and soil wood) and woody residue (table 7). Each of these soil organic components has a unique chemical and physical character based on the type of organic materials present and the nature of underlying mineral soil. Consequently, each organic material supports specific microbial populations and contributes to rooting activities that affect tree growth.

Woody residue can be any size, but material larger than 7.5 cm in diameter can become a long-term component of the soil ecosystem. Wood less than 7.5 cm in diameter usually decays rapidly and is converted to soil humus or consumed by fire (Edmonds 1991, Reinhardt and others 1991). Often, organic matter content in large woody residue may equal or surpass that of other soil components (table 7). Generally, the amount of woody litter in undisturbed stands increases as site moisture conditions improve and as fire hazard decreases.

Woody residue decay is primarily a function of invertebrate activity, the colonization of wood by white-rot and brown-rot fungi, and the microclimate of the soil surface (Edmonds 1991, Harmon and others 1986). Because most woody residues in eastside forests are from conifers, brown-rot fungi largely control the decay patterns. Initial sapwood decay is usually of the white-rot type, which eventually shifts

Table 7—Soil organic content in old-growth forests of the northern Rocky Mountains

Site	Yield capability	Woody residue	Forest floor	Soil wood	Mineral soil[2]	Total	Proportion in mineral soil
	m3ha-1yr-1	Mg ha [1]					%
Cedar/hemlock (Montana)	7.7	83	50	51	145	329	44
Subalpine fir (Montana)	7.7	146	36	36	153	371	41
Cedar/hemlock (Idaho)	9.5	154	23	48	201	426	47
Douglas-fir (Montana)	4.9	45	26	37	133	241	55

[1] From Jurgensen and others 1990

[2] Sampled to a depth of 30 cm. These values do not include root weights.

to brown-rot. Heartwood is generally decayed by brown-rot fungi. Brown-rot fungi thrive under the following conditions: high temperatures, low moisture, acid pH, and increased wood lignin content (Larsen and others 1980).

“Soil wood” is the term used to describe conditions where woody residues become incorporated into the forest floor. Soil wood is often covered by litter and not noticed as a soil component. For the inland Pacific Northwest, soil wood can comprise more than 15 percent of the organic matter in the uppermost 30 cm of soil (table 7). Soil wood amounts generally increase as stand productivity increases. On highly productive sites, soil wood can equal or surpass other kinds of organic matter in the forest floor. Virtually all soil wood is of brown-rot origin, and usually comes from large residues with appreciable amounts of heartwood. Pine species and Douglas-fir are particularly good sources for soil wood, which can remain in the soil for hundreds of years (Harvey and others 1981, McFee and Stone 1966).

The forest floor is a combination of three recognizable layers: the litter layer (O_i), consisting of freshly fallen needles, twigs, and other debris that have undergone only slight decomposition; the fermentation or duff layer (O_e), plant materials undergoing active decomposition but still identifiable; and the humus layer (O_a), unrecognizable, dark brown or black, amorphous organic material that has undergone extensive decomposition. Both the duff and humus layers are usually permeated with fungal mycelia and root mats. The extent of forest floor development is a function of litter inputs and decomposition rates, fine root turnover, previous stand management, and fire history (Edmonds 1991).

Surface mineral horizons in eastside forests also contain significant amounts of organic matter, especially if the soil has a significant volcanic ash content (table 3). The surface 30 cm of mineral soil is the zone of greatest importance, since root numbers (and presumably root activity) decrease rapidly below this depth (Kimmins and Hawkes 1978, Strong and LaRoi 1985). The surface 5 to 10 cm of mineral soil is a transition zone below the humus layer, which has high organic matter content (table 3) and root numbers. Deeper mineral soil has a lower organic and nutrient content and lower available water-holding capacity (tables 4 and 6).

Total soil organic content generally reflects site productivity, being highest in moist cedar/hemlock or white fir stands and lowest on dry ponderosa pine sites (table 7). High-elevation subalpine fir stands are an exception because low temperature limits both organic-matter decomposition and tree growth. Organic matter in the forest floor, soil wood, and surface mineral horizons usually make up less than 15 percent (by volume) of the top 30 cm of soil (Harvey and others 1976b). Normally, however, this 15 percent has the highest concentrations of nutrients (especially N), has a substantial cation exchange capacity, and supports most of the N-fixing and ectomycorrhizal activities. This uppermost 15 percent is also the part of the soil most likely to be disrupted or destroyed by forest management activities (Page-Dumroese and others 1991). Deeper soil horizons, however, can be important to tree growth, especially on dry, sandy soils, and can be subjected to compaction by heavy equipment (Cochran 1985, van Rees and Comerford 1986).

The Effects of Forest Management Operations

Nearly all forest management operations can alter the cycling of aboveground organic materials and their subsequent incorporation into the soil. In the past, timber removal was not considered detrimental to site productivity because of long stand-rotation ages and the large amounts of organic matter usually left after harvest. Recent trends towards increased woody residue removal and intensive site preparation, however, have raised concerns about how such management affects soil processes and site productivity (Harvey and others 1976a, McColl and Powers 1984). Most of these concerns have focused on possible soil nutrient losses, or changes in nutrient availability (Smith 1985, White and Harvey 1979). The contribution of organic matter to soil nutrient cycling is a major concern; however, the loss of organic matter may additionally affect such soil characteristics as water-holding capacity, aeration, drainage, and cation exchange, and may greatly affect long-term productivity.

Clearcut harvesting, which is used in this region to manage for early successional species such as Douglas-fir, causes greater losses of soil organic matter than other harvesting systems. Historically, clearcutting operations have included forest floor removal (exposing mineral soil); the control of competing grasses, shrubs, and trees; followed by prescribed burning or scarification (Graham and others 1989a). Clearcutting operations remove much of the woody residue and surface soil organic matter present on a site, though amounts vary according to the intensity of the treatment and the distribution of organic matter in the soil (table 8). Soils containing higher proportions of organic matter in woody residue on the forest floor are more affected by these operations than soils containing higher portions of surface mineral layers.

Table 8—Surface organic contents after clearcutting and site preparation

Soil component	Residue treatment[2]			Uncut
	None	Prescribed burned	Intensive removal	
Cedar/hemlock (Idaho)	Mg[3]	Mg	Mg	Mg
Wood residue	146.0	57.9	10.6	154.3
Forest floor	16.7	5.5	13.3	23.2
Soil wood	50.9	22.4	51.6	47.9
Total	213.6	85.8	75.5	225.4
Subalpine fir (Montana)				
Wood residue	..	55.2	43.7	145.7
Forest floor	..	30.2	35.8	36.0
Soil wood	..	37.6	43.2	35.9
Total	..	123.0	122.7	217.6

[1] From Jurgensen and others 1992.

[2] Site was clearcut to a 12.7-cm-diameter top. Residue treatments: none, residue left; prescribed burned, broadcast burned in the fall; intensive removal, residue removed by blading with a crawler tractor.

[3] Dry mass ha⁻¹ of organic material on top of mineral soil.

Losses of organic matter from forest floor and mineral soil after timber harvesting are generally a result of increased organic matter decomposition by soil microorganisms (Hendrickson and others 1982). High soil moisture, temperature, and alkalinity after harvesting—especially if fire is used for slash disposal (table 9)—

increase microbial activity (Hungerford 1980, Jurgensen and others 1981). Mixing of the forest floor into the mineral soil during harvest and site preparation also increases rates of organic matter decomposition and the release rate of nutrients (Salonius 1983). This mixing effect is more pronounced when site preparation follows logging (Graham and others 1989a). Many of the practices that caused deleterious effects have been dramatically changed in recent years, however (Meurisse 1988).

Table 9—Soil moisture and temperature on a cedar-hemlock site in northern Idaho after clearcutting and site preparation treatments [1]

Soil component	Residue treatment [2]							
	None		Prescribed burned		Intensive removal		Uncut	
	H2O %	Temp deg C	H2O %	Temp deg C	H2O %	Temp deg C	H2O %	Temp deg C
Forest floor	88	15.4	43	14.3	104	15.3	90	11.7
Soil wood	158	13.4	122	12.8	206	12.4	232	11.4
Mineral soil [3]	47	12.0	38	11.5	61	10.7	41	10.5

[1] From Jurgensen and others, 1992.

[2] Site was clearcut to a 12.7-cm-diameter top. Residue treatments: none, residue left; prescribed burned, broadcast burned in the fall; intensive removal, residue removed by blading with a crawler tractor.

[3] Mineral soil to a depth of 30 cm.

Site preparation is often critical to attaining satisfactory stocking of seedlings in eastside forests. Site preparation in this region is primarily by burning or mechanical means, such as soil scarification or scalping (Gutzwiler 1976). Mechanical equipment, such as dozers and grapple pilers, can remove most woody residue or displace the forest floor and surface mineral soil over large areas. Such extensive machine piling, windrowing, or soil scarification significantly affect subsequent seedling establishment and growth (Graham and others 1989b, Minore and Weatherly 1988). Prescribed burning can also be used effectively to reduce fuel loadings and prepare the soil for planting, but care is needed to ensure that such operations do not remove too much organic matter and adversely affect site productivity.

When regeneration is established from seed, removing large amounts of soil organic matter by various site preparation techniques to expose mineral soil is sometimes desirable (Shearer and Stickney 1991). Normally, however, such extensive soil disturbance is not required if the site is planted with nursery stock. Site preparation methods used before planting seedlings would be less intensive than those used for seedbed preparation, and would have less effect on soil organic content (Harvey and others 1987). How much postharvest organic matter to leave will be influenced by whether the stand is to be established by planting or by relying on natural regeneration. When using natural regeneration, however, managers must always be aware of the risk that extensive seedbed preparation may have on soil organic matter reserves, which are needed for subsequent stand growth and development.

Loss of organic horizons during harvesting and site preparation may seriously reduce site productivity, stability, and regeneration potential. Studies worldwide have shown that high rates of organic matter removal from forest sites are linked to substantial long-term growth reductions of various conifer species (Ballard and Will 1981, Farrell and others 1986, Smith 1985, Weber and others 1985). Substantial losses in productivity have been reported in the northern Rocky Mountains as a result of forest-floor or surface soil displacement and soil compaction, 15 to 25 years after clearcutting (Bosworth and Studer 1991, Clayton and others 1987). Consequently, postharvest treatments should be planned to limit damage to fragile organic horizons—especially for the high-stress, diseased stands common in many areas of eastern Oregon and Washington. Often these stands have heavy fuel loadings that warrant intensive site treatments and forest floor removal to achieve adequate regeneration. Even on these sites, however, productivity will be maintained or improved by conserving as much organic matter as possible.

After harvesting timber on these sites, a large amount of woody residue is added to the soil surface. How much should be left to become part of the soil organic supply will depend on stand species composition, amount of decay and defect, rates of wood utilization, and whether any site preparation is used (Harmon and others 1986, Harvey and others 1989a). Often, however, woody residues after harvesting and site preparation are less than what was present before harvest (table 8). During harvest, large decayed logs, which are very important to soil nutrient and microbiological processes, are often destroyed or fragmented (Jurgensen and others 1992).

In general, more woody residue can remain on cooler, wetter habitat types (subalpine fir and Engelmann spruce) than on the warmer, drier ones (Douglas-fir and ponderosa pine). A minimum value of 22 to 36 metric tons ha⁻¹ of residual woody material has been recommended to maintain long-term site productivity on such moist sites (Harvey and others 1987). Leaving more wood could benefit many sites, but might create a significant fire risk. After considering fire hazard and various other site preparation objectives, Reinhardt and others (1991) established a fairly wide range of allowable woody residue loadings (22-125 metric tons ha⁻¹) for mixed conifer forests in the northern Rocky Mountains. But for drier sites in this region, this recommendation is likely high. Site-specific woody residue guidelines are needed for the generally dry, high stress forests in eastern Oregon and Washington.

Perspectives for Eastside Ecosystems

Soil organic matter is an important factor in the continued productivity of eastern Oregon and Washington forests. Compared to soil conditions in preharvest old-growth stands, timber harvesting and extensive site preparation displaces or destroys surface soil organic matter over large areas. Such organic matter losses have important implications for soil chemical, biological, and physical properties, especially on infertile sites that are prone to drought. Severe wildfires would have similar consequences. Removing large woody debris, which is the source of soil wood, may also have considerable consequences for long-term site productivity.

Maintaining adequate amounts of organic matter on many forest sites in eastern Oregon and Washington may increase the risk of wildfire and favor the activity of certain root-rotting fungi. Careful prescribed burns or mechanical site preparation, however, can be practiced on most sites with relatively little effect on soil organic content. On the very dry sites in this region, with their historically low soil organic and N content and high fire potential, this situation will be the most difficult to resolve.

THE MICROBIOLOGY OF EASTSIDE SOILS

The Soil as a Biological Entity

Traditionally, some have viewed soil as inert and inanimate, and soil properties have often been perceived as distinctive but relatively unchanging—except for plant nutrients—and based on mineral constituents. The organic horizons have, until recently, been largely ignored. Soil microbes have also been ignored, except for a few high-profile organisms (such as soil-borne pathogens and mycorrhizal fungi). Predictions by forest growth models have keyed almost exclusively on vegetation, gross land form, and site characteristics—the aboveground characteristics of the last rotation were assumed to be the best indicator for predicting growth, ignoring soil and related soil-borne processes. If soil potential was reduced, the assumption was that fertilizing could offset any damage. This approach has fostered a significantly over-optimistic view of the health and productivity potential for second generation forests (Gast and others 1991, Powers 1991).

Contemporary studies indicate that soil quite literally resembles a complex living entity, living and breathing through a complex mix of interacting organisms—from viruses and bacteria, fungi, nematodes, and arthropods to groundhogs and badgers. In concert, these organisms are responsible for developing the

most critical properties that underlie basic soil fertility, health, and productivity (Amaranthus and others 1989, Harvey and others 1987, Jurgensen and others 1990, Molina and Amaranthus 1991, Perry and others 1987). Biologically driven properties resulting from such complex interactions require time lines from a few to several hundreds of years to develop, and no quick fixes are available if extensive damages occur (Harvey and others 1987).

Microbial Ecology

The variety of organisms residing in forest soils are extensive; all contribute to soil development and function, some in very critical ways (Amaranthus and others 1989). Although this section concentrates on the microbes (primarily bacteria and fungi), we recognized that several orders of insects, earthworms, and burrowing mammals make significant and sometimes critical contributions to organic matter decomposition, soil mixing, and microbe propagule movement within many forest soils (Molina and Amaranthus 1991, Wilson 1987).

The numbers and biomass of microbes in forest soil can be staggering; for example 10 to 100 million bacteria and actinomycetes, 1000 to 100,000 fungal propagules, and several kilometers of hyphae (fungal strands) can be present in a single gram of soil (Bollen 1974). The biomass related to such numbers is also staggering. Old-growth Douglas-fir forests of the Pacific Northwest can contain 4200 kg/ha dry weight of fungal hyphae and 5400 kg/ha of ectomycorrhizal root tips alone (Fogel and others 1973). Bacterial biomass could equal or exceed fungal biomass, and the total biomass of an inland cedar/hemlock forest should be very nearly comparable to a coastal Douglas-fir forest. Thus, microbial biomass in eastside forests could easily reach 10,000 kg/ha and are a force to consider in management methods.

Input to soil structure—The role of microbes in producing structure in non-agricultural soils is often overlooked. The development of soil and the stability of its structure is a direct result of the input of complex carbon compounds to the soil. Much of this carbon input and the conversion processes are mediated or facilitated by microbes (Amaranthus and others 1989, Perry and others 1987). Structure greatly affects the pore distribution in the soil, especially the large pores that permit the storage of water and rapid movement of air on which plant roots are highly dependent. Thus, maintaining structure is critical to soil productivity and sustainability, and because the processes are dynamic, they require a constant high rate of carbon input, conversion, and loss.

Aboveground and belowground processes are tightly interconnected. Photosynthetic plants fix carbon and transport it to the roots and soil via leaf litter; soil microbes then reprocess, convert, and store the carbon. Soil carbon is ultimately released back to the atmosphere by microbial (and other small animal) respiration. Thus, aboveground and belowground productivity are directly connected, not only via direct transport of carbon to roots, but also through the production of organic litter. Microbial decomposers convert plant litter into soil components through the activities of several groups of organisms directly associated with plant root systems. By way of the interconnected microbial community, native plants modify the soils in which they grow. Up to 80 percent of a stand's annual carbohydrate production may be invested in supporting the mycorrhizal feeder-root system (Fogel and others 1973). At least 15 percent of annual energy production is directed to mycorrhizae. This high rate of energy distribution indicates how critical belowground microbial processes are to aboveground growth potential (Read 1991).

Rhizosphere—Perhaps the most interesting and dynamic microenvironment in forest soil is the rhizosphere—the region within 2 mm of any root surface. The root surface is termed the rhizoplane. Both the rhizoplane and the rhizosphere tend to have more available high-energy substances—sugars, starches, gels, amino- and organic-acids, for example—than soil away from roots. High-energy substances are derived both from the sloughing of cellular materials (root caps, surface cells) and from the leakage of materials directly through root cell walls (Molina and Amaranthus 1991). The rhizosphere of young roots tends to have the highest concentration of leakage products. Generally, rhizosphere substance concentrations vary with the age, season, health, and species of plant.

Microbial communities inside the rhizosphere are quite different from those outside. Outside, the soil organisms can generally derive energy from the breakdown of complex organic molecules contained in a wide variety of organic debris, including wood (Edmonds 1991, Fogel and others 1973). Organic debris is an important source of energy for free-living, N-fixing microbes in all inland Western forest soils (table 10).

Table 10—Contribution of surface organic materials to nonsymbiotic nitrogen fixation in three old-growth forests of the inland Northwest (Jurgensen and others 1991)

Soil component	Subalpine fir (Montana)		Cedar-hemlock (Montana)		Cedar-hemlock (Montana)	
	Mg [1]	%N fix [2]	Mg	%N fix	Mg	%N fix
Woody residue	145.7	35	83.2	27	154.3	49
Forest floor	36.0	22	49.7	23	23.2	3
Soil wood	35.9	17	50.5	11	47.9	7
Mineral soil	..	26	..	39	..	41

[1] Dry weight (metric tonnes/ha) of organic material on top of mineral soil.

[2] Percentage of total nitrogen-fixation.

Rhizosphere organisms contribute a wide variety of products to the soil environment (Molina and Amaranthus 1991). Many simply metabolize root exudates into complex organics, adding them to the soil mixture. Others, however, contribute directly to the plant by releasing otherwise unavailable nutrients from the soil (Chanway and Holl 1991), providing direct pipelines from soil to root cells (such as with mycorrhizal fungi) and directly competing with root pathogens for a variety of nutrients (Molina and Amaranthus 1991, Perry and others 1987). Also, the rhizosphere is home to a wide variety of root-damaging organisms, such as low-grade pathogens, feeder-root diseases, and root-rotting organisms. Infection of the root by mycorrhizal fungi often provides resistance to low-grade and feeder-root pathogens (Marx 1972, Zak 1964). The rhizosphere is another important microenvironment for nonsymbiotic N-fixing microbes that again can be important to soil N enrichment in Western forest soils (Dawson 1983, Li and Hung 1987, Rambelli 1973).

Compared to other soil environments, the rhizosphere region is an extremely competitive, energy rich environment. Without the appropriate vegetation, the contributions of this important microenvironment to forest soil development are lost.

The effects of symbionts on soils—Important microbes affected by the rhizosphere environment are various symbionts. The most important symbionts are: ectomycorrhizal fungi that infect tree roots to form functional “short roots,” and a small group of bacteria and actinomycetes that infect plant roots to form N-fixing structures (“nodules”) on legumes and other N-fixing plants. Both provide N directly to the host; both directly affect the rhizosphere environment and the supporting plant; and both parasitize the plant, taking energy but supplying nutrients in return (Amaranthus and others 1989, Jurgensen and others 1990, Molina and Amaranthus 1991, Perry and others 1987).

The presence of N-fixing nodules provides host plants direct access to atmospheric N, making them far less dependent on soil N supplies. Mycorrhizal roots are distinctive, complex structures on tree and other forest plant roots in which a similar trade occurs. The invading fungi take energy from the plant, and, in return, greatly extend the root system access to soil nutrients by supplying nutrient release and transport mechanisms through the hyphal/rhizomorph (fungal root) networks in soil. As reported earlier, several kilometers of fungal hyphae have been recorded in a single gram of soil. This hyphal network also creates its own functional rhizosphere, termed the mycorrhizosphere (Rambelli 1973). Interconnections between fungal individuals within hyphal and rhizomorph networks are common (Perry and others 1989).

Plant to plant connections via mycorrhizae make possible an interconnected network among individuals and within complex stands (between overstory and understory, for example) (Perry and others 1989, Read

and others 1985). Root grafting in eastside ecosystems is largely limited to within an individual tree, occasionally between individuals of the same species, but only very rarely between species. But within species, mycorrhizal networks are potentially limited only by the host range (number of species of hosts that the fungus can infect). Some fungi have very wide host ranges; thus, a stand can be extensively interconnected—aboveground to belowground, belowground between roots, between individuals (of the same or different species), or between groups of individuals—and even between one generation and the next (Perry and others 1989). So, in addition to nutrient movement in the soil via micro or macro pores, cracks, root channels, and so on, living conduits within and among higher plants and fungi provide a network for extensive exchange of nutrients and metabolites. This system is best developed in eastside forests within surface soil horizons that contain organic matter (table 11).

Table 11—Cumulative depth (centimeters of organic soil strata) and distribution of active ectomycorrhizal short roots in organic and mineral strata within and between sites (Harvey and others 1986)

	Cumulative depth/core of organic horizons	Total ectomycorrhizal short root-tips in	
		Organic horizons (all)	Mineral horizons (all)
	cm	Percent	
Old growth			
Western hemlock, Montana	3.8	[1] 89 a	11 b
Subalpine fir, Montana	3.5	93 a	7 b
Western hemlock, Idaho	2.5	89 a	11 b
Douglas fir, Montana	2.3	76 a	24 a
Western white pine, Idaho	2.0	93 a	7 b
Ponderosa pine, Washington	1.7	16 a	84 b
Grand fir, Idaho	1.5	70 a	30 a
Subalpine fir, Wyoming	.7	71 a	29 a
Second-growth (Montana)			
Pole sized lodgepole	1.9	82 a	11 a
Pole sized mixed conifer	1.8	89 a	11 a
12-year-old western larch	1.5	31 a	69 b
Pole sized Douglas-fir	1.2	66 a	34 a
Pole sized ponderosa pine	.6	86 a	14 a
12-year-old lodgepole pine	.5	76 a	24 a

[1] Differing letters indicate significant differences ($p = 0.05$) within site, based on two-sided t-test of numbers of short-root tips in combined strata

Can individuals (or groups) parasitize one another, that is to say, move nutrients or photosynthate around within a stand to balance temporary shortfalls? Such movement has yet to be widely demonstrated, except in simple microcosms (Read and others 1985), but it seems likely, particularly on highly variable sites that include harsh or infertile environments (Perry and others 1989). Positive responses of trees, to both the presence of ectomycorrhizae and to associated N-fixing plants, are demonstrable and common (Harvey and others 1991, Jurgensen and others 1990). A wide variety of external climatic and soil

variables may condition this response, but maximum plant dependency on microbial symbionts seems most likely on inherently harsh or damaged sites (Boucher and others 1982, Harvey and others 1991, Perry and others 1989).

Nutrient channeling and cycling—The above descriptions of microbial structures and processes suggest that they are likely to provide highly critical conduits for the input and movement of materials within soil and between the soil and the plant. Nitrogen and carbon have been mentioned and are probably the most important. Although the movement and cycling of many others are mediated by microbes, sulfur, phosphorus, and iron compounds are important examples (Amaranthus and others 1989, Molina and Amaranthus 1991).

The relation between forest soil microbes and N is striking. Virtually all N in eastside forest ecosystems is biologically fixed by microbes (Boring and others 1988). Only a small amount of N comes into eastside forests directly from the atmosphere as precipitation or dust (probably less than 2 kg/ha per yr), except downwind from major pollution sources. Next to temperature and moisture, availability of N is probably the most limiting factor in forest productivity (Boring and others 1988, Jurgensen and others 1990). Most forests, particularly in the inland West, are likely to be limited at some time during their development by supplies of plant-available N (Miller and others 1992). Thus, to manage forest growth, we must manage the microbes that add most of the N and that make N available for subsequent plant uptake.

Symbiotic N fixation is the most efficient process by which forest sites acquire N from the atmosphere; however, the process depends on development and vigor of appropriate hosts. Generally, hosts are best suited to this function and most vigorous (with attendant high fixation capacity) during the early stages of forest development. For old-growth or heavily shaded conditions, hosts are much reduced in numbers and vigor (Borman and Gordon 1989). Unfortunately, relatively few hosts are present at any stage, and their ability to support fixation depends on high plant vigor (Jurgensen and others 1990). Release of N from these host plants can be slow. If internal demand for N is high until it dies and decomposes, the plant may release very little N, except as falling leaves and fine root turnover. The harshest, most infertile sites have the greatest need for added N, but the most efficient N fixation depends on limited hosts growing under good conditions that are not often available. So, because some eastside forest sites are relatively harsh, they are unlikely to meet long-term N requirements from this source.

The other principal source of soil N is nonsymbiotic fixation by free-living microbes that depend on the breakdown of soil organic materials for the energy to fix N (Jurgensen and Davey 1970). Nitrogen input potential from this source is much lower than from symbiotic fixation (table 12). The fixation process is energy intensive, but energy available from the breakdown of soil organic matter, or leaked from other organisms, is much lower than that supplied to symbiotic N-fixers by host plants. In addition, nonsymbiotic N-fixers are not efficient in breaking down complex soil organic matter directly; they depend on their ability to scavenge energy-containing materials released as byproducts of activities from other organisms, primarily decomposers. Thus, energy availability for this process is limited and depends on other groups of organisms. Substantial N fixation often occurs in rhizosphere and mycorrhizosphere environments, however, because of the availability of high-energy leakage products there (Dawson 1983, Li and Hung 1987). Despite the generally low rates of N input from nonsymbiotic N fixation, this source of N is usually constant and N is rapidly released because of the short life span of the microbes; this source is sustained throughout the life of a forest stand and increases with organic matter accumulations characteristic of dense or old-growth forests (Jurgensen and others 1990). Both amounts of organic matter and rates of N fixation are important; either can be critical in eastside forests.

Decomposition and pathogenesis—A major characteristic of western forests is the tendency to accumulate fixed carbon (Olsen 1963). Ecologically speaking, the photosynthetic process is less limited in this environment than microbial respiration—the process that drives decomposition. Resulting excess carbon (accumulated fuel) and frequent lightning can combine to aid the recycling process through wildfire, an essential decomposition force in these ecosystems (Habeck and Mutch 1973, Olsen 1981). In

the absence of fire, plant nutrients would eventually be locked away in accumulating debris, turnover would be slow, and ecosystem development would be severely impaired. Thus, biological decomposition and fire support the nutrient turnover required for vegetation to develop over long periods of time, especially in relatively harsh, infertile environments. Even subtle differences in temperature, moisture, or both can change this balance and the resulting fire regime (Harvey and others 1979, Olsen 1981). Fire cycles can vary widely between climatic regions, but, in the absence of human intervention, a relatively stable balance between fire and microbial decomposers is normal within a climatic region.

Table 12—Nonsymbiotic nitrogen fixation in forests of the Western United States

Forest type	Location	N fixation (kg N/ha/yr)	Reference
Douglas-fir			
Old growth	Oregon	1.0	Sollins and others 1987
	Oregon	1.4	Silvester and others 1982
	Montana	0.8	Jurgensen and others 1991
Various ages	Montana	0 - 1.0	Jurgensen and others 1987
23-yr-old	Oregon	0.4 - 1.1	Heath and others 1988
Subalpine fir			
Old growth	Montana	0.7	Larsen and others 1978
Various ages	Montana	0 - 1.7	Jurgensen and others 1987
	Montana	1.5	Jurgensen and others 1991
Cedar-hemlock			
Old growth	Idaho	2.9	Jurgensen and others 1991
	Montana	0.8	Jurgensen and others 1991
Various ages	Idaho	0 - 4.3	Jurgensen and others 1987
	Montana	0 - 1.8	Jurgensen and others 1987
Mixed conifer			
Various ages	Idaho	< 0.1 - 4.8	Harvey and others 1989
120-yr-old	British Columbia	0.3	Cushon and Feller 1989
Lodgepole pine			
80-yr-old	Wyoming	< 0.2	Fahey and others 1985
Aspen - mature	Utah	0.6	Skujins and others 1987

Insects and diseases are part of a balanced ecosystem that includes fire, biological decomposition processes, and the development of vegetative communities that thrive in the temporally and spatially variable, resource-limited eastside environment (Harvey and others 1992). Although usually viewed as pests at the tree and stand scale, insects and disease organisms perform useful functions on a broader scale. The role of native soil pathogens will be highlighted in this discussion. Root disease fungi, for example, can infect both individuals and localized groups of individuals (stands). Fungi can be devastating at these scales. Annual losses from individual tree mortality can be 2 to 3 percent, and productivity losses to 30 percent are common in inland Western forests (Byler 1984, Filip and Goheen 1984). We have seen stands where productivity has essentially ceased because of root disease fungi.

Most insects and diseases, including root-rot organisms, tend to select stressed hosts (Waring 1987). Stress-selection can provide increased "recycling" of individuals or groups of host plants that are not well suited to their current environment. For example, if geographically and climatically diverse systems are often visited by fire, some vegetation becomes stressed by the attendant rapid changes. Removal of stressed vegetation facilitates rapid replacement; and many "pests," including root-rots, facilitate early and rapid decomposition and recycling of nutrients from such potentially maladapted hosts (Harvey and others 1992).

Decomposers and pathogens can play various, interactive roles. Time, space, and ecosystem change are important variables in these roles. What may be devastating to individual trees or stands at a given moment may provide long-term ecosystem benefits (Harvey and others 1992). Fundamental potential (climate, soil) of forest sites should first be matched to appropriate vegetation and stand characteristics at each stage of development, fully considering the historical norms under which the vegetation developed. Then, forest management through manipulating pest damages has a much greater chance of success.

Pests are a part of even the healthiest eastside ecosystems. Pest roles—such as the removal of poorly adapted individuals, accelerated decomposition, and reduced stand density—may be critical to rapid ecosystem adjustment. But these roles need not be fulfilled at maximum rates over extensive areas at any one time; when they are, the cause is more fundamental than simply pest activities out of control (Harvey and others 1992). In some areas of the eastside and Blue Mountain forests, at least, the ecosystem has been altered, setting the stage for high pest activity (Gast and others 1991). This increased activity does not mean that the ecosystem is broken or dying; rather, it is demonstrating functionality, as programmed during its developmental (evolutionary) history.

Soil Microbes as Ecosystem Drivers

To reemphasize, photosynthetic plants produce basic foodstuffs that build plant bodies. These bodies provide energy sources for microbes. Microbes, in turn, drive many of the most critical ecosystem processes that create the total environment in which plants grow, especially the soil environment (Harvey and others 1987, Jurgensen and others 1990). Microbes are responsible for the input of N; those that attack living plants (inclusive of insects) directly regulate the genetic nature of plant populations, both individually and collectively, and also regulate population dynamics (Burdon 1990, Linhart 1991). Microbes are also the primary intermediaries for required communications between plant to soil, soil to plant, and plant to soil to plant, as well as movement of material within the soil (Amaranthus and others 1989, Perry and others 1989).

Soil Microbes and Microbial Processes as Indicators of Health and Productivity

From an ecosystem perspective, the mere presence of pests may not indicate long-term forest health problems. Such damage, however, may sometimes be a useful indicator depending on our understanding of other ecological questions.

Because they are critical for ecosystem development and function, microbes will, no doubt, eventually be used to measure transfer rates between roots and soil of critical nutrients and metabolites. Acid rain and pollution-caused reductions of ectomycorrhizal fungi are well documented in parts of Europe (Arnolds 1991, Cherfas 1991, Rühling and Soderström 1990). Similarly, microbes are highly sensitive to the presence of a variety of toxic materials (Fritze 1992). Population changes for specific organisms should be good indicators of the presence of toxins in the system. Examples are the effect of heavy metal pollutants and organic toxins on both fleshy fungi and leaf-inhabiting fungi (Hawksworth 1990, Nordgren and others 1985). In addition, fungi, like some higher plants, can accumulate heavy metals (Rizzo and others 1992) and might serve as a sink for damaging pollutants, even at extremely low concentrations.

Fungi should be particularly useful as forest health indicators because they form visible fruiting bodies (such as mushrooms). Unfortunately, timing and density of fruiting is highly responsive to weather, and thus, may not be easy, particularly because our knowledge of fungal community dynamics in forested ecosystems remains limited. Observations in Europe, however, suggest that dramatic reductions in the diversity and population density of forest floor fungi may be a direct result of extensive pollution (Cherfas 1991). Forest managers should remain alert to changes in potentially polluted areas. Lichens are also useful indicators of air pollutants, probably because of the importance of the fungal component in their combined fungal and algal structures and their near total dependence on aerosol nutrients (Eversman 1985).

Plants without chlorophyll are common in inland Pacific Northwest forest ecosystems. At least one group of these plants depends on interconnections with chlorophyllous hosts through mycorrhizae. These are relatively small but easily seen herbaceous plants, such as Indian-pipe (*Monotropa uniflora* L.) and pinedrop (*Pterospora andromedea* Nutt.). They use common infection by the mycorrhizal fungus as an indirect means of parasitizing an energy-producing host. Thus, their presence, population size, and behavior may provide valuable clues as to the health and diversity of the mycorrhizal community and its respective hosts. Much research remains to be done on these plants.

Eastside Perspectives

Microbial processes are fueled primarily by plant debris that is concentrated in and most characteristic of organic horizons. These horizons are shallow, subject to site disturbance (tables 8 and 11), and thus easily changed or destroyed. These ecosystems have evolved to accommodate natural disturbances, primarily by wildfire and climate, as well as a wide range of pest activities; however, these ecosystems have not developed under circumstances that exclude fire, or that include soil compaction or extensive physical dislocation of soil horizons. Any of these factors can pose short-term risks. Fire especially, when it occurs after excessive fuel buildup, may be severe and highly damaging to soil systems. Also, compacted soil layers will eventually return to original conditions only after long periods of time. Ecosystem damage from these factors is likely to be detrimental to the full range of microbe functions.

FIRE AND EASTSIDE SOILS

General Effects of Fire on Forest Soils

Several reviews of fire effects on soil are available in the literature (Harvey and others 1989a, Hungerford and others 1991, Viro 1974, Wells and others 1979), and only a brief summation of these general effects will be given here. Fire has been an important factor in the development of forest ecosystems and soils in eastern Washington and Oregon. The role of fire changed with the arrival of Europeans, but its effects continued to be important to soils and ecosystems in this area, both by its exclusion and its use. Some ecosystems depend on fire for establishment; others depend on fire to develop certain successional paths (Weaver 1974). In addition to the direct effects of fire on soil, changes in ecosystem type or path can also indirectly change soil properties and processes.

The effects of fire on soils are numerous and highly variable, depending on the type and intensity of the fire and the amount of surface fuels consumed. Fire can affect soils physically, chemically, and biologically; it can alter nutrient cycles, soil development, and site productivity. If litter or the critical organic (O) horizons are not entirely destroyed by fire, then fire effects on soil are usually minimal.

Fires generally have little effect on soil physical properties, but high intensity fires can make clay soils coarser and more erodible (Chandler and others 1983) or affect soil porosity and structure (Dyrness and Youngberg 1957). If fire removes all of the litter layer, raindrop impact can alter the structure of the soil at the surface, decrease porosity, and increase bulk density; these changes will also reduce water infiltration and increase surface runoff and soil erosion (McNabb and Swanson 1990). Fire can also cause water-repellent layers to form in soils, and decrease water movement down the soil profile (DeBano and others 1976). Microclimatic effects of fire depend on whether the understory or both the understory and overstory are consumed. Removal of understory vegetation can increase solar radiation to the soil surface and increase air and soil temperatures, but it may have little effect if the overstory is undisturbed. Soil moisture can be increased or decreased by fire, depending on whether soil infiltration is reduced (decrease in soil water) or vegetation is removed (reduces interception and transpiration and increases soil water).

Changes in soil chemical properties or soil processes largely result from the loss of protective woody debris and O-horizon material. Carbon is volatilized from organic matter and litter above 200°C and N

above 300°C. Consequently, N can be lost from soils with fires of moderate intensity (Hungerford and others 1991). Phosphorus and (S) can be volatilized at temperatures of 750 to 800°C and are not normally lost except by very high-intensity fires (Hungerford and others 1991). Major cation nutrients contained in organic matter, such as Ca, Mg, and K, are not normally lost through volatilization, but deposited in ash as oxide and carbonate salts, with trace amounts of phosphates. These salts are highly soluble, particularly those of K, and can be leached from the soil with high rainfall (Viro 1974). Ammonification and nitrification are enhanced immediately after fire, but ammonium and nitrate usually return to pre-burn concentrations within a few years after fire (Jurgensen and others 1981).

Normally, these nutrients are readily available for plant uptake after fire, and create short-term increases in soil fertility that can last several years. If the organic matter of the mineral soil is reduced (as happens with a high-intensity, long-duration fire), however, the cation exchange capacity of the soil is also reduced and the ability of the soil to retain nutrients leached from ash decreases. The increase in cations other than hydrogen or aluminum and the loss of organic acids from decomposition also increases soil pH, a change that can be beneficial to many plants and organisms. A decrease in organic acids and an increase in pH can reduce podzolization (a soil-forming process creating an acidic, highly leached soil). Hall (1980) has suggested that repeated fires could alter the rate of podzolization in forest soils.

Fire effects on soil flora and fauna vary widely with fire severity, soil type, and individual organisms. Bacteria are killed at temperatures of 110 to 210°C (wet and dry soil, respectively), and fungi are killed at 60 to 120°C (Wells and others 1979). Severe fires sometimes sterilize soil, but low-intensity fires may cause only short-term effects on soil flora. Death of soil organisms can disrupt ecosystem functions because flora and fauna that decompose organic matter, mycorrhizae, N-fixers, and other organisms are essential to element cycling. Bissett and Parkinson (1980) found that fire changed the relative prominence of different soil organisms, and believed that the successional path of the soil flora in O horizons had been altered by fire. The effects of fire on mycorrhizae vary, but severe fires can suppress mycorrhizae in the top 10 cm of soil (Wright and Heinzelman 1973) or decrease mycorrhizae by consuming soil organic substrates (Harvey and others 1976b). Fire sometimes also controls root diseases (Ahlgren 1974), but increases infection in other cases by creating infection courts in damaged roots (Litke and Gara 1986). The effects of fire on soil fauna are less well known, but are believed to decrease populations, although effects may be less and of shorter duration (Ahlgren 1974).

Many of the effects of fire on soils and vegetation alter the nutrient cycle of the burned ecosystem. Woody debris, the O horizon, and understory and overstory organic matter are either partially or totally consumed. Water inputs (precipitation can be altered by the amount of condensation on foliage) and outputs (leaching) can be affected by fire, as well as by processes within the soil ecosystem. The movement of nutrients through plant and soil organisms is an essential part of the nutrient cycle, and the elimination of vegetation or soil flora and fauna will drastically alter the ecosystem cycling rates in the short term. The rates of transfers and transformations of elements within the ecosystem can be changed by the loss of organisms responsible for decomposition and nutrient immobilization, reduced plant uptake and litter-fall, differences in soil water movement (changes in transpiration and evaporation), and other effects. Nutrient cycling will eventually adjust to changes caused by even severe fires, but excess available nutrients can be lost from the site until cycling rates increase.

In the late 1800s, the pattern of fire in the inland Pacific Northwest changed with the coming of Europeans. With this change, forest and range soils and ecosystems were shifted to a different successional direction. In a geologic sense, this change in soil processes has been brief and is reversible. In human timeframes the effects appear long-lasting. Pre-1900 fire conditions and soil properties and processes will be considered briefly here; then, an examination will be made of how this shift in fire pattern has altered current soil properties and processes.

Pre-1900 Fire Conditions and Eastside Soils

Before the late 1800s, burning of forests and ranges by Native Americans was common and frequent (Arno 1985). Because of the high frequency and resulting low fuel build-up, most of these burns were

probably not high-intensity fires, and did not have long-lasting effects on soil. The practice may have loosened nutrient cycles by rapidly changing litter to available nutrients, but, depending on the fire frequency, this change may have had little effect on site productivity. Most wildfires of this time were probably of similar intensity and effect. The ecosystem type and location of a burn is most important in determining how much a fire affected soil, largely because fire frequency was correlated with the ecosystem type and elevation (Agee 1993 (table 2)).

Pre-1900 fires were frequent in low-elevation ponderosa pine and Douglas-fir forests and in range lands throughout the inland Pacific Northwest. How many of the fires were caused by Native Americans is now known, but comparisons of fire frequency between habited and uninhabited areas suggest that native burning was a primary factor in the short fire frequencies in many areas (Gruell 1985). Most Native American fires were in low-elevation areas, but they undoubtedly spread to high-elevation forests at times; most high-elevation fires are believed to have been caused by lightning (Arno 1985). Little information is available on pre-human fire conditions of eastside forests.

Knowledge of the general effects of fire on soils can be used to estimate the effects of fire on physical, chemical, biological, and nutrient cycling of both high- and low-elevation forest soils. Frequent under-burning of low-elevation ponderosa pine and Douglas-fir probably had little effect on soil properties because most of these fires were probably of low intensity, but would have affected some aspects of nutrient cycling. Fire would accelerate litter decomposition and provide a periodic flush of available nutrients. The periodic reduction of understory vegetation would release captured nutrients and reduce atmospheric N fixation, if N-fixing plants were prominent on the site. The effects of fire on high-elevation true fir and lodgepole pine forests are probably similar to the effects of fire today, that is, highly variable. In areas of low fire frequency and high fuel buildup, fires may consume large amounts of woody debris and the O horizon. This consumption could subject shallow soils to a serious loss of productivity by reducing the organic matter that is essential for maintaining soil structure, water retention, organism population structure, cation exchange sites, and erosion prevention (Harvey and others 1989a).

Post-1900 Fire Conditions and Eastside Soils

Studies comparing pre-1900 forest and range ecosystems of the inland Pacific Northwest with post-1900 conditions generally indicate a buildup of fuels and biomass in forests since 1900 (Gruell 1983, van Wagtendonk 1985), largely a result of fire suppression in the region, which has changed soil processes and the response of soils to fire. In general, when wildfires occur now in the inland Pacific Northwest, they are of much greater intensity because of high fuel loading (van Wagtendonk 1985). Two common results of the high fuel loading are loss of all forest floor material and combustion of much large woody debris, and heating of the mineral soil, causing a loss of soil organic matter, organisms, structure, and cation exchange capacity.

Because of fuel buildup, wildfire effects on inland Pacific Northwest forests can be much greater than wildfire effects before 1900 (Brown 1983). Normally, three factors determine the extent of wildfire effects on site productivity: ecosystem type, fire intensity, and frequency of fire (Klock and Grier 1979). Fire sometimes acts as a means of releasing nutrients stored in organic matter that, because of moisture or temperature limitations, normally decomposes extremely slowly.

Grier (1975) examined the effects of a high-intensity fire on a mixed conifer forest on eastern slopes of the Cascade Range in Washington. Wildfire resulted in a loss of 96 percent of the forest floor biomass and 97 percent of the forest floor N. Grier estimated that 39 percent of the ecosystem N was lost. Volatilization and ash convection also resulted in losses of 35 percent of the K, 11 percent of the Ca, and 15 percent of the Mg. Throughout much of the burn area, the entire forest floor was consumed. The thick ash layer over the mineral soil contained high accumulations of nutrients, however, and these nutrients were not lost by leaching below the rooting zone during the first year after the wildfire. Helvey (1980), examining the effects of the same fire for seven years, found runoff and stream sediment in the second and subsequent years was double that before the burn, probably resulting in accelerated nutrient loss into the stream system.

Post-1900 Prescribed Burning and Eastside Soils

Prescribed fires are usually intended to reduce slash loading after timber harvesting, to facilitate planting or regeneration, and reduce fire hazard. Prescribed underburning to reduce surface fuels and understory vegetation can also reduce fire hazard. As with natural fires, the effects of prescribed fires on forest soils are highly variable.

The most common use of prescribed fire is to reduce slash, either by broadcast burning or piling slash and burning (Graham and others 1989a). Usually confined to small areas, piling and burning slash usually results in consumption of all organic matter underneath the pile and extensive soil heating. The effects of broadcast burning depend on the severity of the fire; severity is controlled by moisture conditions at the time of fire, management of the fire, slope, and the type of area burned. Sites with fire regimes adapted to frequent fire are less likely to be negatively affected by prescribed burning than are sites where fire is rare (McNabb and Cromack 1990).

Most well-implemented broadcast burns result in limited loss of organic matter and exposure of mineral soil which minimize soil effects. McNabb and Swanson (1990) state that because fire severity is usually limited, mineral soil loss after prescribed fire is usually minor. Highly erodible soils, or steep slopes can combine with high-intensity rainfall to cause erosion if too much mineral soil is exposed. Jurgensen and others (1981) found that no long-term depletion of soil N resulted from prescribed broadcast burning of slash on a subalpine fir site, and that regeneration benefited through increased soil N availability.

Prescribed burning usually causes only short-term reductions in populations of fungi and soil invertebrates and can increase bacteria (Borchers and Perry 1990), but these effects vary depending on the site and fire severity. Harvey and others (1980a, b) found that broadcast burning in partial cuts either reduced or rapidly eliminated mycorrhizae in clearcuts of Douglas-fir/larch forests in western Montana. At a high-elevation forest in eastern Washington, Lopushinsky and others (1992) found that broadcast burning resulted in the best seedling performance in the first two years after planting, and that even piling and burning slash positively affected seedling growth. Harvey and others (1989a) recommend limiting the use of site preparation methods that disturb shallow soils because of possible root damage and loss of organic matter. They recommend broadcast burning at low to moderate intensity.

Studies of underburning in inland Pacific Northwest forests to reduce fire hazard and to develop open stands are not as common as those of slash disposal. Landsberg (1992) found decreased ponderosa pine growth in central Oregon with prescribed underburning and greater losses of soil nutrients at sites with low fertility. Nissley and others (1980) found that losses of N and S with prescribed underburning was correlated to fuel consumption. They measured N losses of 38 percent and S losses of 43 percent from the forest floor. Further examinations of prescribed underburning may be necessary to determine the relative costs and benefits of this procedure, but, in general, well managed prescribed fires do not appear to damage most forest sites.

Applying Fire in Eastside Forest Management

Fire has been both used and excluded from forests of the eastside in recent times. Fire as a tool has potential both to damage and enhance ecosystems and productivity. Where prescribed burns are used properly, their benefits (for example, reduced fire hazard, obtaining natural regeneration, better planting spots allowing more careful planting) should outweigh the drawbacks. Martin (1981) suggests several techniques for using prescribed burning to maintain or improve soil productivity. Prescribed fires should be implemented on soil types where effects will be minimal (such as Mollisols, and many well-developed Andisols and Inceptisols) and where benefits are most likely. In the future, restrictions on the use of prescribed burning because of air pollution controls may limit the use of fire, unless wildfire hazard reductions and forest health management can justify its continued use.

FERTILIZER APPLICATION AND EASTSIDE SOILS

The Site Factor

Application of fertilizers to complex ecosystems in highly diverse environments, typical of eastside forests, poses interesting challenges (Miller and others 1992), particularly for forests that are stress- and mortality-prone, and where ecosystems and soils may be sensitive to the effects of disturbances. A primary problem is the extreme variation in physical and soil environments across short distances with a superimposed, highly variable climate and complex vegetation structures—that is, with four to ten conifer species occupying many forested sites.

The Vegetation Factor

In general, inland Pacific Northwestern trees have adapted to their environment either by maintaining high genetic plasticity—that is, being broadly adapted to a range of environments, as are, for example, western white pine, western larch and, to a lesser extent, ponderosa pine (Minore 1979; Rehfeldt 1982, 1986; Rehfeldt and others 1981), or by being very closely adapted to specific environments, as are Douglas-fir, the white firs, and lodgepole pine (Hamrick 1976; Minore 1979; Rehfeldt 1979, 1983). Environmental or genetic “generalists” operating well within their environmental range will be the most predictable targets for fertilization in highly variable, frequently disturbed environments. Conversely, closely site-adapted species, such as genetic or environmental “specialists,” will be the most difficult targets for fertilization.

Nutrients like N are likely to have significant effects on the phenology of eastside species, and, therefore, their effects may be even more unpredictable than with other nutrients. Applications of N to many tree species are likely to induce major changes in the distribution of C between tops and roots, generally favoring the production of tops at the expense of roots (Alexander and Fairley 1983, Brix 1983). Generating forest stands with high ratios of tops to roots in ecosystems with periodic drought and soils of limited moisture and nutrient storage capacity could be risky.

Managing stress in treated stands could be the determining factor governing the net benefits of applying fertilizers. The resulting stress ecology cannot be analyzed without examining the interactions of stress, pests, and selected microbial activities that are important to eastside forests.

The Pest Factor

High stress predispose forests to pest attacks (Horn 1985, Karban and others 1988). Also, increasingly specific evidence indicates that several important native root pathogens normally resident in the most productive eastside ecosystems may be highly attuned to host stress (Entry and others 1991, Matson and Waring 1984, McDonald and others 1987). Native pests, especially root diseases, may perform critical functions in ecosystems. Perhaps most important of the native, soil-borne diseases are *Armillaria* and *Phellinus* root rots. Fertilizers may result in delayed stress reactions and increased damage caused by various pests, particularly root diseases. For several fertilizer plots throughout northern Idaho, this indeed may be true (Moore and others 1993).

Native, soil-borne diseases like *Armillaria* and *Phellinus* are also sensitive to soil physical and chemical characteristics (Blenis and others 1989, Entry and others 1991, Horn 1985, Matson and Waring 1984, Rykowski 1981, Swift 1968) and to nutrient balance or metabolic byproducts in host trees (Entry and others 1991, Moore and others 1993). Thus, direct addition of nutrients may influence root diseases with or without alteration of stand stress (Rykowski 1981, Swift 1968).

The Soil Biological Factor

Beneficial microbial activities may also play an important role in the regulation of fertilizer effects. Direct effects of fertilizer on the structure of the soil microbial community have also been reported (Arnebrandt

and others 1990, Laiho and others 1987). A general reduction in microfungi activities could disturb the competitive balance between organism types or between products resulting from the activity—for example, the balance of saprophytes to pathogens or N conversion and fixation products. The specific reduction of mycorrhizal activities in stands after fertilization (Alexander and Fairley 1983, Laiho and others 1987) raises the possibility of significantly reduced ability to acquire nutrients, particularly if large root-to-shoot ratios and intense mycorrhizal inputs are required on low productivity or harsh sites (Keyes and Grier 1981). Mycorrhizal activities lead directly to increased resistance of trees to root diseases of many types (Cervinkova 1990, Marx 1972, Zak 1964), thus, any reduction of mycorrhizal activities after fertilization raises the possibility of increased feeder-root disease problems.

Opportunities

Although applying fertilizers to the sensitive and complex ecosystems characteristic of eastside ecosystems appears somewhat risky, it does offer some opportunities. Applying N at 225 to 560 kg/ha has increased growth of eastside type forests (Shafii and Moore 1989). Many sites are likely to respond to N because it and moisture are normally the limiting factors for growth of inland forests (Jurgensen and others 1979, Sharii and Moore 1989). Thus, using N fertilizer offers an excellent opportunity to enhance growth in stands specifically managed for maximum growth, especially with widely adapted species on relatively good sites. Rust-resistant white pines growing on good pine sites, especially those with high soil-moisture storage capacities, represent the best possible opportunity for maximum response with minimum risk. Young stands with high proportions of white pines, western larch, and ponderosa pine may also benefit, especially if sites are within the high-productivity end of their geographic range on good soils. Sites with very low N—for example, those heavily disturbed by site preparation or wildfire, and with indigenous vegetation acclimated to higher N concentrations than on the disturbed site—might also be highly responsive to fertilizer (Harvey and others 1989a). This treatment could offer useful site amelioration; the added N should help alleviate stress and might solve pest problems rather than make them worse. Although accelerating growth with N additions appears attractive, care must be exercised not to bring about shortages of other nutrients. Reduced K and K-mediated metabolites in tissues of N-fertilized stands may be a contributing factor to increased susceptibility of N-treated trees to root diseases and other pests (Moore and others 1993).

INFLUENCE OF WEATHER AND STAND ON SOIL WATER USE IN PONDEROSA PINE

A modeling exercise that evaluated moisture input to eastside forest soils during a 95-year period and the rates of use of that moisture by forest stands of various types was based on plot data from both above and below the ground. This exercise allowed evaluation of the potential for forest stands to generate more biomass than available moisture input and storage could support. Under such conditions, stand stress is increased and the potential for health problems is very high. Implications for forest health management are covered in the summary and conclusion.

Do current forest problems result from changes in climate, management-related changes in vegetation, or a combination of causes? Insofar as stands located near Bend, Oregon, are representative, these questions can be analyzed with the following ecosystem process models.

Demonstration Stands

Long-term weather records were examined from stations throughout the inland Pacific Northwest for evidence of differences in crop-year maximum and minimum average temperatures and total precipitation. Long-term crop-year total precipitation, average maximum, and average minimum temperatures for Spokane and Vancouver, WA, and for Moscow, ID, from NCDC (National Climatic Data Center)

weather station data supplied on CD-ROM (Earth Info, Boulder, CO) provided basic climatic data. The Wickiup Dam record, the local station, covered the period from 1943 to 1990. This record was extended back to 1895 by linear regression of the climate records from Wickiup Dam and from the three long-term stations, 1943 through 1989.

On the basis of low r^2 values for temperatures and high values for precipitation (table 13), specific years were selected to stand in for the early record at Wickiup Dam on the basis of precipitation. The Vancouver record showed good agreement with Wickiup Dam (table 13), but this record covered the period from 1900 to 1989. To extend back to 1895, the record from Moscow was used because of a better r^2 (table 13). Years were selected from Wickiup Dam to simulate its early record by sorting Vancouver and Moscow data and then selecting the closest year to the target year. We concluded that weather in the vicinity of Wickiup Dam is probably little or no different today than 90 years ago (tables 14 and 15).

Table 13—Regression coefficients for three Pacific Northwest stations and the Wickiup Dam record for the years 1943 through 1989

Independent station	Dependent station	Maximum temperature	Minimum temperature	Precipitation
Moscow, Idaho	Wickiup Dam	.23	.00004	.26
Spokane, Washington	Wickiup Dam	.1	.12	.18
Vancouver, Washington	Wickiup Dam	.14	.006	.58

Table 14—Reconstructed from crop year (August 1 to July 31) weather record for Wickiup Dam showing target year precipitation from section station actual year precipitation from section station and actual record year temperatures (degrees F) and precipitation (inches) at Wickiup Dam

Moscow records				Wickiup Dam record		
YEAR	PPT	YEAR	PPT	MAXT	MINT	PPT
1895	(17.31)	1945	(17.78)	57.10	26.40	13.58
1896	(17.79)	1945	(17.78)	57.10	26.40	13.58
1897	(23.04)	1943	(22.99)	58.90	25.40	29.95
1898	(21.77)	1949	(21.29)	59.50	25.20	14.54
1899	(23.43)	1959	(24.62)	59.70	33.10	14.85
5-year average				58.50	27.30	17.30
Vancouver Records						
1900	(47.30)	1951	(47.11)	55.40	26.90	24.81
1901	(43.29)	1963	(43.30)	58.40	30.70	24.24
1902	(40.64)	1975	(40.60)	57.10	29.10	19.34
1903	(42.84)	1963	(43.30)	58.40	30.70	24.24
1904	(42.32)	1965	(42.27)	58.80	29.70	20.33
1905	(34.62)	1966	(34.48)	57.00	28.50	19.24
1906	(35.95)	1957	(36.01)	57.70	30.60	22.67
1907	(42.78)	1971	(42.59)	55.40	28.20	24.99
1908	(37.27)	1953	(37.24)	56.60	28.50	22.67
1909	(36.67)	1967	(36.32)	58.20	30.50	18.08
1910	(42.34)	1965	(42.27)	58.80	29.70	20.33
1911	(35.46)	1960	(35.05)	58.30	30.40	18.49
1912	(33.12)	1973	(32.88)	56.50	29.30	13.99
1913	(36.96)	1964	(37.10)	57.60	30.40	16.69
1914	(38.79)	1952	(39.09)	56.20	28.80	17.42
20-year average				57.64	28.93	19.70

Table 15—Actual summary records for Wickiup Dam 1970-89 for crop year August 1 to July 31 in degrees F and inches

Actual year	Fill-in year	MAXT	MINT	PPT
1970	1980	58.20	31.30	20.06
1971	1971	55.40	28.20	24.99
1972	1972	57.00	30.00	22.57
1973	1973	56.50	29.30	13.99
1974	1974	56.20	29.60	29.48
1975	1975	57.10	29.10	19.34
1976	1976	56.50	29.10	16.86
1977	1977	58.70	29.70	10.64
1978	1978	57.70	31.80	24.45
1979	1979	57.00	29.50	16.05
1980	1980	58.20	31.30	20.06
1981	1981	58.70	31.00	21.57
1982	1943	58.90	25.40	29.95
1983	1983	54.80	31.20	31.53
1984	1984	56.50	30.70	25.84
1985	1985	56.30	28.70	19.35
1986	1986	56.30	29.30	27.18
1987	1987	58.80	31.60	19.97
1988	1988	60.20	29.90	19.12
1989	1989	58.40	30.10	23.25
Last 5-yr average		58.00	29.90	21.77
20-yr average		57.37	29.84	21.81

Old-Growth and Regeneration on the Same Plot

To compare conditions before and after forest management began, we needed stand information. Stand data were collected in 1988 to compare stand structures before and after management (Cochran and Hopkins 1991). These authors measured second-growth diameter on nineteen 0.4-acre plots at each of three areas near Wickiup Dam. The first area, Sugar Cast, is 18 miles northeast of the dam on a flat site about 12 m higher than the 1310-m elevation of the dam. Its long-term average rainfall was estimated to be 53.3 cm (Larsen 1976). Fort Rock, the second area, is on a flat site at 1554-m elevation about 8 miles east of Sugar Cast. Long-term rainfall here was 45.7 cm (Larsen 1976). Both belong to the ponderosa pine climax series of plant communities (Volland 1976); plot records showed no white fir. The third area, Bend Ranger District, is 10 miles northwest of Sugar Cast, 8 miles west of Bend along the Century Loop Road. Elevation of this site is 1615 m and long-term rainfall was judged at 88.9 cm (Cochran, personal communication). The two plots selected here supported more than 5 percent area covered by white fir, which places them in the mixed-conifer climax series (Volland 1976).

Diameters of heartwood and sapwood of stumps and snags left after a 1920 logging operation were measured. Stumps were destructively sampled to develop regressions for estimating diameters at breast height and total height of trees represented by the stumps. (See appendix B for the equations used.) See Cochran and Hopkins (1991) for computational details for the regeneration. All the stump data on 0.4-acre plots and the first 30 trees of the second-growth stands were used with these regressions and other equations (see appendix B) to estimate volumes, basal area, trees per hectare, average diameter, stem carbon, leaf carbon, respiration surface, and all-sided leaf area index. Percentage of basal area in sapwood was estimated for each old-growth stand directly from the stump measurements. A published regression was used to estimate the sapwood area of both the stumps and second-growth (Hunt and other 1991). The compiled plot specific data are listed in table 16.

Table 16—Individual plot parameters for old-growth and regeneration on 6 plots in the Deschutes National Forest in central Oregon.

Plot	Stand	Trees/ha	BA m ² /ha	Avg DBH cm	Avg HT m	Avg SW%	STEM C kg/ha	RESP V m ³ /ha	LAI (1) m ² /m ²	COVER %
FR10	old-growth	119	18.7	43.2	21.0	35	36939	11.6	4.3	25
	regen	459	21.8	23.8	13.0	86	9519	11.3	12.3	37
	regen	459	21.8	23.8	13.0	37	9519	9.2	5.2	37
FR16	old-growth	56	10.1	45.7	21.4	79	20,831	10.5	5.3	14
	regen	489	26.9	26.0	13.8	86	11,869	13.8	15.2	35
	regen	489	26.9	26.0	13.8	37	11,869	11.2	6.5	35
SC1	old-growth	81	18.0	47.2	23.7	79	46,231	24.0	10.5	22
	regen	729	33.9	22.9	17.8	76	14,988	21.1	17.1	44
	regen	729	33.9	22.9	17.8	37	14,988	18.4	8.2	44
SC2	old-growth	44	17.4	68.3	28.9	94	46,905	24.2	10.6	20
	regen	585	34.9	26.8	17.0	77	15,633	19.6	17.6	39
	regen	585	34.9	26.8	17.0	37	15,633	16.7	8.4	39
BRDI	old-growth	113	30.2	53.8	24.6	69	80,024	36.2	14.9	36
	regen	729	35.2	23.1	13.3	59	12,708	16.0	13.4	51
	regen	729	35.2	23.1	13.3	37	12,708	14.8	8.5	51
BRDQ	old-growth	113	49.1	70.3	29.2	82	142,000	65.4	26.5	56
	regen	1389	31.7	15.3	9.7	66	10,378	15.5	14.3	47
	regen	1389	31.7	15.3	9.7	37				

Accuracy of the sapwood basal area regression to predict old-growth percentages of sapwood (%SW) was tested by plotting residuals of measured %SW on predicted %SW (figs. 1, 2, and 3). On the white fir plots (Bend), the regression overestimated %SW (fig. 1). The regression yielded a constant 86 percent but plot I averaged 69 percent, with a range from 0.35 to 0.94; and plot Q averaged 82 percent with a range of 0.68 to 0.94. On the high-quality ponderosa pine climax plots (Sugar Cast 1 and 2, fig. 2), plot 1 averaged 85 percent (± 0.61 to 0.98) and plot 2 averaged 94 percent (± 0.90 to 0.95). The regression would provide about the same stand value of leaf area index as the actual measurements (fig. 2). Plots 10 and 16 in the Fort Rock area (fig. 3) were quite different. Plot 16 was like Bend plot I. It averaged 79 percent (± 0.56 to 0.91). Plot 10 was unlike any other (large negative deviations in fig. 3). It averaged 37 percent sapwood and ranged from 21 to 44 percent. These values were much like small diameter trees found on other plots. A %SW of less than 50 was used to signify oppressed individuals or dominants growing on a moisture-limited site. The significance of this plasticity will be evident later.

BEND RANGER DISTRICT RESIDUALS

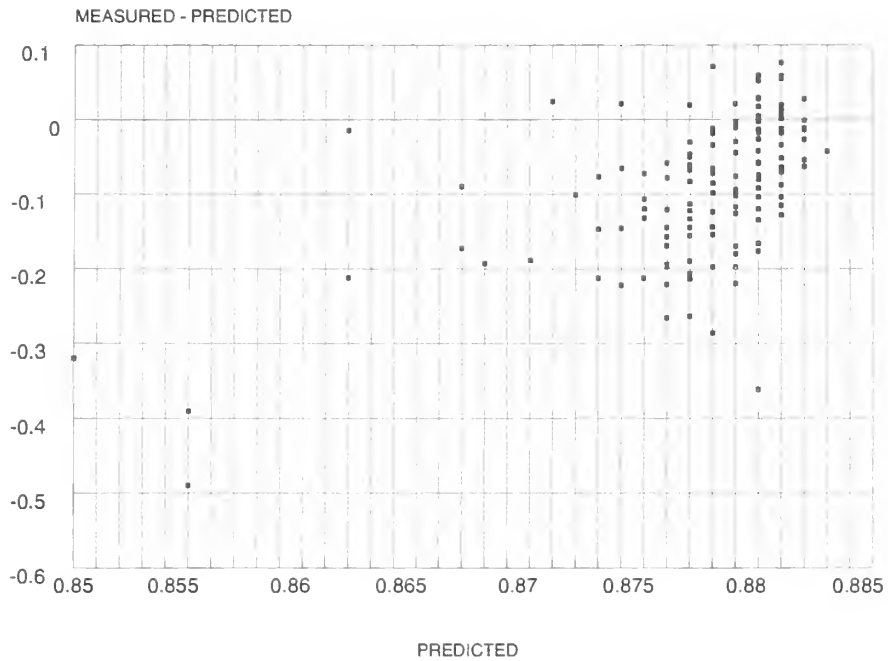


Figure 1. Residuals of percentage sapwood measured and predicted from regression. Sapwood and heart-wood diameters measured on old-growth ponderosa pine stumps located on Bend Ranger District plots I and Q of the Deschutes National Forest and belonging to a mixed-conifer plant association.

SUGAR CAST RESIDUALS

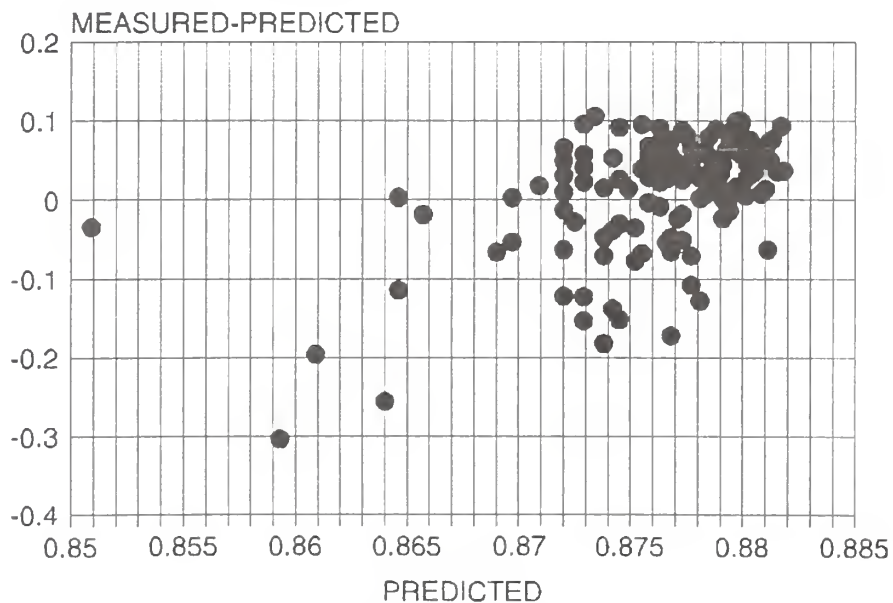


Figure 2. Residuals of percentage sapwood measured and predicted from regression. Sapwood and heart-wood diameters measured on old-growth ponderosa pine stumps located on sugar cast plots 1 and 2 of the Deschutes National Forest and belonging to a ponderosa pine plant association.

FORT ROCK RESIDUALS

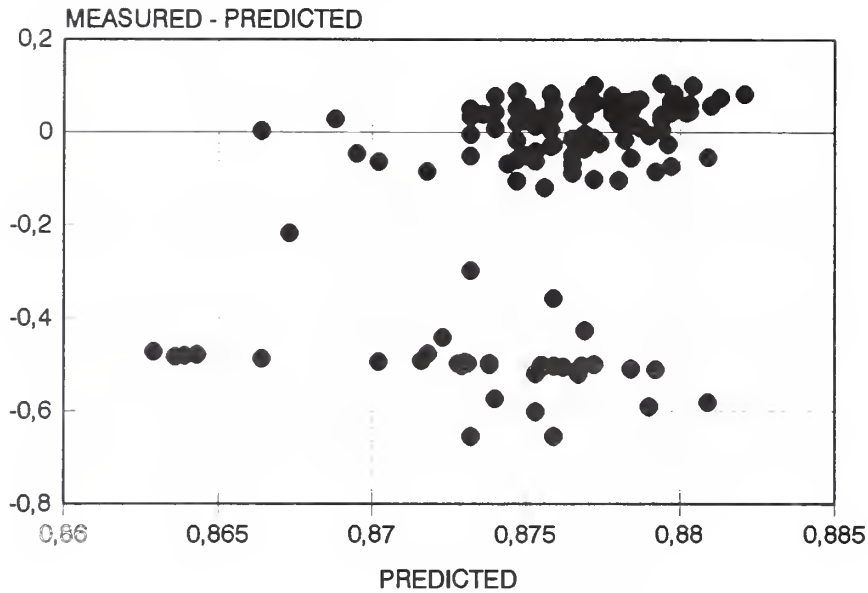


Figure 3. Residuals of percentage sapwood measured and predicted from regression. Sapwood and heart-wood diameters measured on old-growth ponderosa pine stumps located on Fort Rock plots 10 and 16 of the Deschutes National Forest and belonging to a ponderosa pine plant association.

Plot specific data (table 16) were used to initialize the mountain climate simulator (MTCLIM, Hungerford and others 1989), the snow accumulation and melt model (SNOWMELT, Foltz 1987), and the individual-tree-based forest ecosystem process model (TREEBGC, Korol 1993). A dry year (1945) and a wet year (1986) from the Wickiup record were run through MTCLIM to translate the record for the three plot areas. The MTCLIM parameter of most influence was elevation, because the plots were nearly flat (table 17). Accordingly, only two runs (wet and dry) were made for each. This set-up and data were used to analyze the effects of weather, site, stand age, soil organic matter, and amount of sapwood on both water use and biomass production (growth) of eastern Oregon ponderosa pine stands.

Table 17—Physiographic constants used to initialize the MTCLIM model for the Bend Ranger District Sugar Cast and Fort Rock plots

Plot	Elevation	PPT ISOHYET	Latitude	Slope	Aspect	East horizon	West horizon
FR10	1554	45.7	43.7	1	102	1	1
FR16	1554	45.7	43.7	6	146	1	1
SC1	1341	53.3	43.7	10	6	1	1
SC2	1341	53.3	43.7	1	340	1	1
BRDI	1615	88.9	44.0	10	43	1	3
BRDQ	1615	88.9	44.0	10	76	1	12
WDDRY*	1310	17.3	43.5	0	0	1	1
WDWET**	1310	21.0	43.5	0	0	1	1

* Base station Wickiup Dam crop year August 1 1944, through July 31 1945, for SNOWMELT runs and January 1 through December 31 1945, for TREEBGC runs.

** Base station Wickiup Dam crop year August 1 1985, through July 31 1986, for SNOWMELT runs and January 1 through December 31 1986, for TREEBGC runs.

Analysis of Weather

To the extent that our reconstruction of the Wickiup record was accurate, annual precipitation during 1895 to 1899 (44 cm average annual) was slightly less than during 1985 to 1989 (44 cm average annual to 55.4 cm). For Spokane and Moscow, this comparison was 43.7 cm vs. 40 cm, and 52.6 cm vs. 59.7 cm, respectively. On a 5 year basis, the two periods were somewhat different. Over a longer term (20 years),

the earliest period may have been slightly drier. The reconstructed Wickiup record (1895-1914) was 19.7 cm, vs. a 1970 to 1989 average of 21.8 cm. Comparable values for Moscow and Spokane were 22.3 cm vs. 26.5 cm and 16.6 cm vs. 16.4 cm.—a very small difference, if any, on a crop-year basis. Thus, if premanagement and postmanagement weather were different, it must be attributed to factors other than available water.

Output from the SNOWMELT model shows some good perspectives. For all plots, the largest difference between wet and dry years was precipitation as snowmelt and evaporation (table 18). Another important point, probably true for most of the forested ecosystems in eastern Oregon and Washington, is that snowmelt (even in dry years) exceeded the highest water-holding capacity of the driest site (Fort Rock 16 water-holding capacity = 1200 m³/ha and dry year snowmelt = 1453 m³/ha). Thus, water storage was more important than water input.

Table 18—Output in m3 of water/ha from the model SNOWMELT for the 6 area x years combinations on the Deschutes National Forest based on MTCLIM output from the Wickiup Dam base station and crop years August 1, 1944-July 31, 1945 (dry) and 1985-86 (wet)

Plot	Snowpack	Total PPT	Rain	Snowmelt	Evaporation
FRdry	1473	3607	1722	1453	432
FRwet	3718	6057	1648	2885	1524
SCdry	1915	4244	1872	1643	729
SCwet	4285	6721	1758	3586	1377
BDRdry	4384	7092	1953	3558	1481
BDRwet	7615	10696	2215	6091	2390

Analysis of Stocking

If the estimates of leaf area index obtained from old-growth reconstruction and the regenerated stands now occupying the 0.4-acre areas are correct, then our data cover the range of possibilities: from large increases in leaf area index with the regenerated stands to old-growth stands exhibiting the largest leaf area indices. Plots FR10, FR16, SC1, and SC2 all showed increases in leaf area index for regeneration, but BRD plot I remained virtually unchanged, and BRD plot Q regeneration produced about 0.5 of the leaf area index of the old-growth stand (table 16). Regeneration in the Fort Rock area increased leaf area index by a factor of three over replaced old growth (table 16). On the better quality Sugar Cast plots, the regeneration was carrying about 1.6 more leaf area index. Undisturbed regenerated stands should carry about 1.4 times their expected equilibria of leaf area indices at about 60 years of age (Long and Smith 1992). Accordingly, the Sugar Cast stands seem correct. The largest unknown is the role of fire in adjusting stocking and leaf area index. Also, the stands studied may have been thinned. In any event, these stands provided an excellent range of both stocking and leaf area indices for model runs.

The Question of Soil Water and Organic Matter

Water-holding capacity of the soil on the plots was estimated from soil maps (Larsen 1976) and land type classes by a soil scientist (D. Page-Dumroese, personal communication,). The Bend plots were estimated as land type 25 with a water-holding capacity of 6 to 10 percent and a depth of 1.25 m to yield 1524 m³/ha. The Sugar Cast plots were estimated as land type 64 with a depth of 1 m and capable of holding 8 to 12 percent water for a capacity of 1200 m³/ha. The Fort Rock plots were in the LX combination of land types 64 and 76. Plot 16 was assumed to be type 64 with the same capacity as Sugar Cast. Type 76 was assumed for plot 10, which has capacity of 4 to 8 percent and depth of 0.76 m to yield 610 m³/ha water-holding capacity.

Recent evidence (Page-Dumroese and others, in preparation) shows that organic matter in the soil profile can increase water-holding capacity and that this effect is pronounced under old-growth canopies. Soils here were assumed to exhibit the following increases under premanagement canopies: Bend Ranger District plots I and Q increase 15 percent; Sugar Cast plot 1 increases 10 percent; Fort Rock plot 16 increases 8 percent; and Fort Rock plot 10 increases 6 percent. These increases were judged on the basis of soil depth and the potential of the site to produce organic matter (D. Page-Dumroese, personal communication). Potential to produce organic matter was keyed to leaf area index for premanagement stands (table 16).

The Question of Phenotypic Plasticity

The Fort Rock 10 combination of old-growth and regeneration was interesting. The average %SW determined for old-growth on this plot (37 percent) was so stable and far removed from the expected value of 86 percent that it forced consideration of phenotypic (physiologically based) adjustment. Appropriate values were computed for respiration volume, stem carbon, and leaf area index for the regeneration at %SW of 37 (table 16). Under this assumption, old-growth and its replacement stand supported nearly identical leaf area indices (table 16). Because %SW might be an important acclimating trait that affords opportunity to adjust water demand to specific conditions (both site and stand), simulation experiments were undertaken to determine TREEBGC on the regeneration stands by using the regression-determined values for %SW (wide sapwood) and a constant 37 percent (narrow sapwood). The assumed phenotypic adjustment of regeneration is illustrated for the water-holding capacity and stand characteristics of the soil at Fort Rock plot 16 (figs. 4 and 5). Daily maximum leaf water potential (parameter B(12) in appendix A) was set at -2 mpa. When soil water reached about 10 to 15 percent of m^3/ha of water, it exceeded that value, which was interpreted as a signal that stomates close and all modeled physiological activities, except maintenance respiration, would cease. Output in the graphs and tables reflect this adjustment.

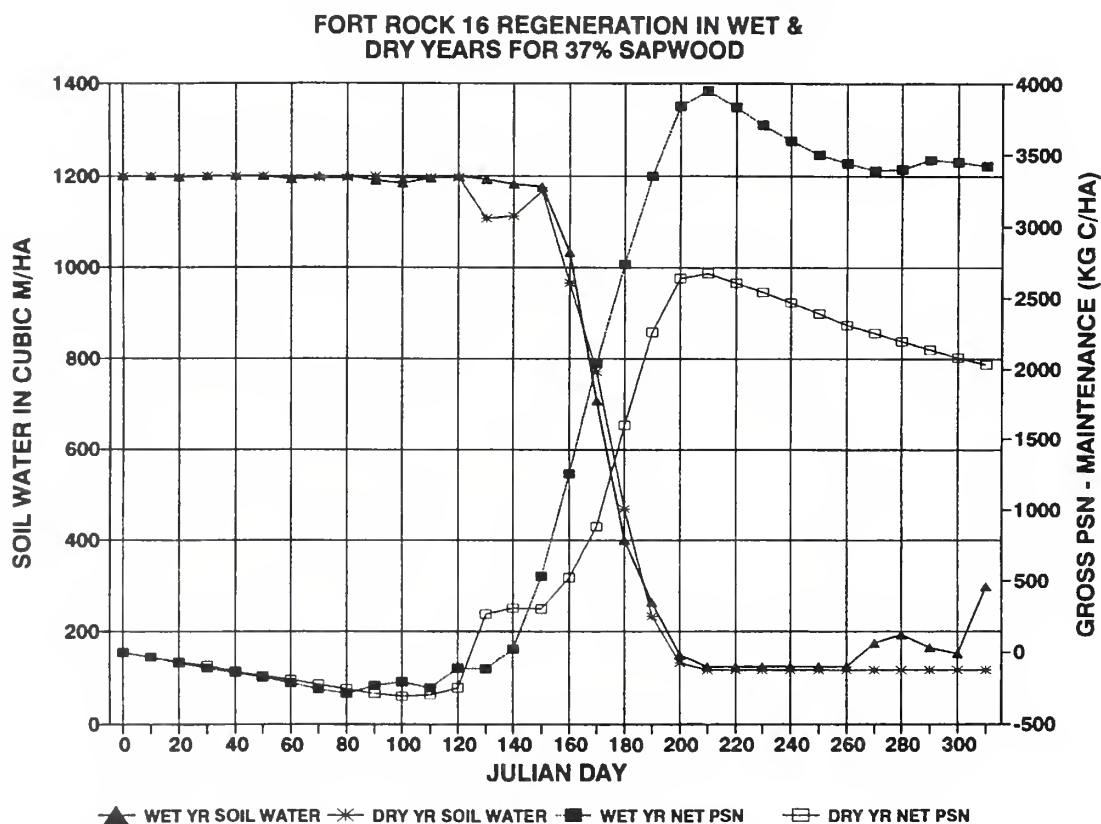


Figure 4. Net carbon and soil water output from TREEBGC initialized by Fort Rock plot 16 regeneration stand data for 37 percent sapwood run on Wickiup Dam weather records for dry and wet years translated by MTCLIM and SNOWMELT weather models.

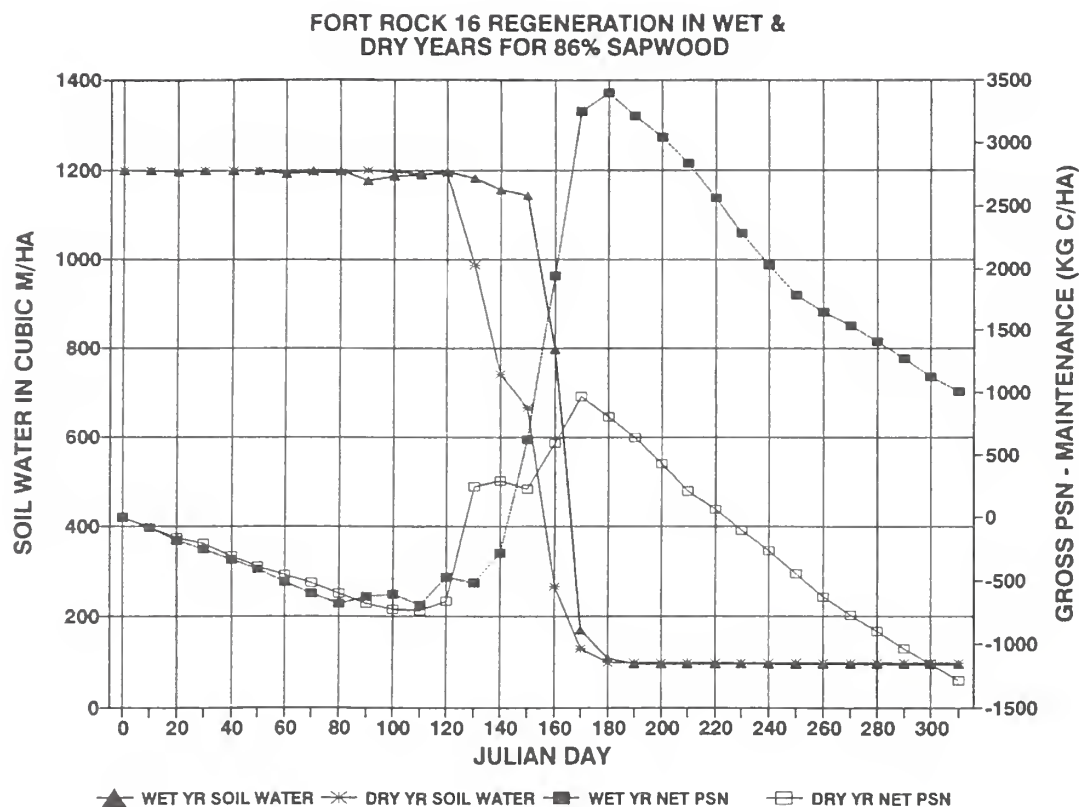


Figure 5. Net carbon and soil water output from TREEBGC initialized by Fort Rock plot 16 regeneration stand data for 86 percent sapwood run on Wickiup Dam weather records for dry and wet years translated by MTCLIM and SNOWMELT weather models.

As shown in both the water-use curves and net carbon gains or losses (growth respiration is not subtracted in the figures) (figs. 4 and 5), phenotypic adjustment could make the stand more competitive. A regenerated stand with 37 percent SW is expected to produce about 3500 kg of carbon/ha (includes growth respiration and maintenance respiration for days 310 to 365) by day 310 during the wet year and about 2000 kg (same inclusions for both figs. 4 and 5) for the dry year (fig. 4). On the other hand, larger maintenance respiration and water demand caused by a higher %SW cause the stand to perform less well (fig. 4). In the wet year, it produced about 1000 kg of carbon; during the dry year, it went into carbon deficit at the rate of nearly 1500 kg of carbon/ha per yr.

A stand composed of trees supporting wide sapwood and functioning as depicted for the dry and wet years (fig. 5) would be expected to have a short life. Either the sapwood basal area regression is wrong or the water-holding capacity of the site was underestimated. This dichotomy brings up a major question about output from these models: Are the results realistic?

Initial Verification of Model Set-up

The physiological parameters used were obtained from an earlier version of TREEBGC known as FOREST-BGC, published by the original authors (Running and Coughlan 1988). TREEBGC contains new routines that allow specific parameterization for tree sizes and respiration volumes (Korol 1993). Constants were used that control water and light processing (Running and Coughlan 1988) for dry ponderosa pine sites in Montana (appendix A). One change from the recommended photosynthesis parameters was made. Inland populations of conifers have a photosynthetic physiology that loses most of its efficiency during winter dormancy (Jurik and others 1988, Koehn 1993, Koehn and McDonald 1991). Also, output from FOREST-BGC for Colorado forests shows a consistent over-estimation of net carbon production (Ryan and Waring 1992). Output from FOREST-BGC using constants, stand data, and

weather from Montana, and adjustments made to account for winter dormancy, showed a 25 percent reduction compared to no winter dormancy constraints (McDonald 1991). Because time and data constraints prevented applying this method, winter dormant chlorophyll was emulated by preventing photosynthesis below 7.5° C (see parameter B(17), appendix A). Parameters for respiration were suggested by Korol (personal communication).

Water-use efficiency was calculated as net biomass (g/m²)/water used (g/m²) to compare model values with published values (Livingston and Black 1988). Their values ranged from 0.0009 to 0.0029 g/g H₂O. Our maximum value from the model was 0.0029 for the narrow sapwood regeneration on BRD plots I and Q for the wet year (tables 22 and 23). As a further test, production efficiency was calculated as net total biomass/projected leaf area index. Production efficiency is defined in terms of net aboveground biomass production (Waring 1983) divided by projected leaf area and includes wood increment + detritus (Gower and Grier 1989). Net carbon (gross carbon fixed - maintenance respiration - growth respiration) was used for the entire plant, and the litter-fall component was assumed to be offset by belowground processes. Biomass was assumed equal to a doubling of carbon production. Our values for production efficiency (figs. 6 through 10) agree well with published values (Grier and others 1992) for eastern Oregon ponderosa pine and values calculated from data presented for Douglas-fir growing in northern New Mexico (Gower and others 1992). We conclude that TREEBGC output, as parameterized for this analysis, was reasonable.

Carbon Production and Pest Susceptibility

An earlier study hinted at a relation between site quality and spruce budworm attack (Shepard 1959). Since then, many papers have forged a direct connection between carbon metabolism and insect and pathogen attack. Sharpe and Wu (1985) presented a model of bark beetle attack based on the interaction between water drawdown and carbon metabolism. Larsson and others (1983) established a stocking experiment in central Oregon ponderosa pine stands to experimentally control vigor: After 10 years, attack rates by mountain pine beetle varied by vigor. Dunn and Lorio (1992) conducted a girdling experiment in southern pines that showed reduced photosynthate supply can lead to increased attack by southern pine beetle and that more than simple carbohydrate concentrations are involved. Redfern (1978) demonstrated in a shade stress experiment that susceptibility of various conifer species to *Armillaria* can be differentially changed according to their shade tolerance. Many other studies have hinted at a link between vigor/stress and host/pest complexes. The following model runs will be interpreted on this basis.

Weather-Soil Interaction Analysis

Ordinating plots according to their water input and storage capacity provides a basis for comparing growth potential and susceptibility of the stand.

Low precipitation and low soil water-holding capacity—On the assumption that maintenance respiration has primary carbon allocation priority, wide-sapwood regeneration on Fort Rock plot 10 (fig. 6) is apparently stressed in both wet and dry years. Narrow-sapwood regeneration showed a slight carbon deficit in the dry year and almost normal growth in the wet year (fig. 6). Little growth or defense happens during the dry year and, depending on storage capacity and frequency of dry years, this stand tends toward a stressed condition.

FORT ROCK PLOT 10

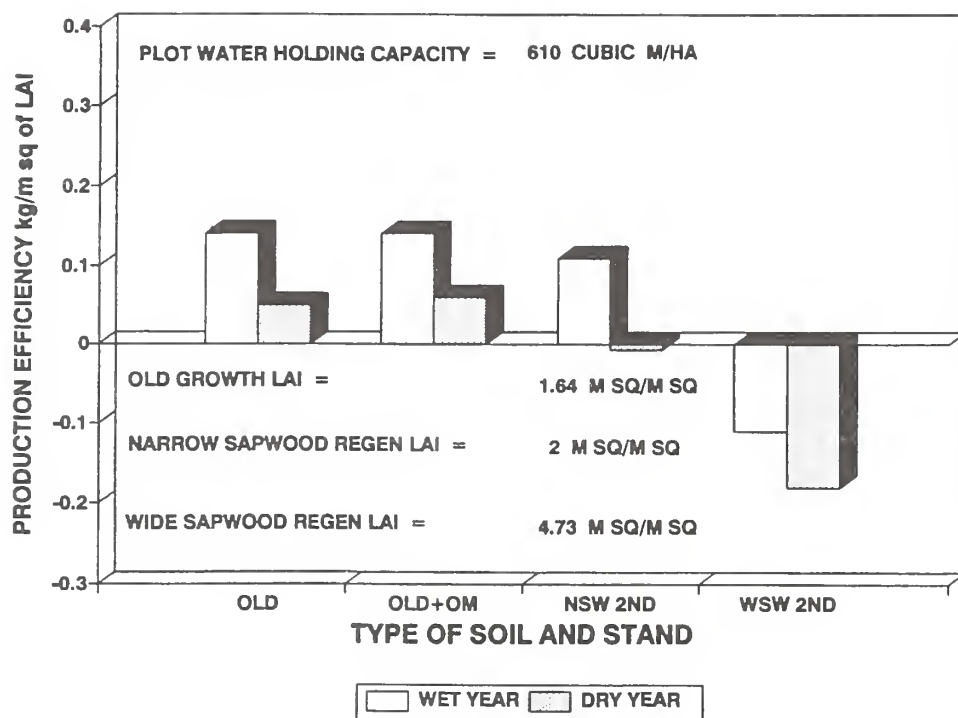


Figure 6. Production efficiency calculated from TREEBGC output after initialization by Fort Rock plot 10 old-growth and regeneration stand data and running on Wickiup Dam weather records for dry and wet years translated by MTCLIM and SNOWMELT weather models. Old + OM = old-growth stand data coupled with organic matter mediated increase in water holding capacity of 6 percent.

How would regeneration compare to the old-growth replaced? The old-growth, with a measured %SW of 37, fared equally well in normal and enhanced soil moisture conditions. Its production efficiency was near 0.14 kg/m². In the dry year, its production efficiency fell only 60 percent (fig. 6). It is not expected to make rapid growth, but would continue in a healthy state. The Fort Rock plot 10 model runs are summarized in table 19 to demonstrate dynamics of a limiting water resource. Two effects of reducing %SW are evident in the table. Respiration was nearly tripled to support the large amount of living tissue, and transpiration was increased, as was gross carbon fixation during the wet year. In the dry year, gross carbon fixation was reduced. Stomates were forced to close 40 days sooner with the high %SW in the wet year and 30 days sooner in the dry year. As expected (Long and Smith 1992), the regeneration stand showed an elevated leaf area index at age 56 but probably not the doubling shown for projected leaf area index under the wide sapwood scenario (table 19). Increased water-holding capacity resulted in only a small increase in production efficiency, from 0.136 to 0.141 and 0.048 to 0.060, respectively, for the wet and dry years. Both old-growth stands should remain healthy throughout either wet or dry years. The narrow sapwood regeneration would probably encounter increasing risk to bark beetles during dry years. This plot was too dry for *Armillaria* (McDonald 1991).

Table 19—Summary of TREEBGC runs over the Julian days of 1 through 365 of old-growth and replacement stands for Fort Rock plot 10 on the Deschutes National Forest for the dry year of 1945 and the wet year of 1986

Situation	Stomate closure	Soil water	Water use	Gross PSN	All RESPIR	Net biomass	WUE*
	Julian day	m3/ha	kg/m2	kg C/ha	kg C/ha	kg/m2	g/g h2O
old wet o	210+	67	113	3413	2251	.232	.0021
old dry o	200	66	98.3	2135	1644	.098	.0010
old wet	210+	62	109.6	3327	2213	.223	.0020
old dry	200	60	95	2048	1654	.079	.0008
2nd wet37	210	55	116.7	3485	2436	.21	.0018
2nd dry37	190	62	102.3	2051	2108	-.012	-.0001
2nd wet85	170	52	170.8	3903	6512	-.522	-.0031
2nd dry85	160	68	127.1	1729	5920	-.838	-.0066

o = water holding capacity increased 6 percent as a result of increased organic matter in soil profile under old-growth and lacking under regeneration.

+ Physiological activity stopped at indicated Julian day but resumed later.

* Water use efficiency $\frac{\text{kg/biomass/m}^2}{\text{kg H}_2\text{O/m}^2}$

Low precipitation and moderate water-holding capacity—Fort Rock plot 16 was assumed to be similar to plot 10, except for doubled soil water-holding capacity. Old-growth %SW was slightly reduced from the expected value to 86 percent. Production efficiency for the old-growth, as well as the narrow sapwood regeneration, showed good balance between wet and dry years (fig. 7). Wide sapwood reproduction was supporting leaf area index three times larger than old-growth; its production efficiency was negative in both years (fig. 7). The old-growth, under both normal and elevated water capacity, showed high potential for added growth with only 8 percent increased water-holding capacity (fig. 7). Its production efficiency increased 1.25 times in the wet year, and 1.2 times in the dry year. Both old growth scenarios were balanced to their environment. Two pieces of information not available for improving this analysis were actual %SW (reproduction) and actual measurement of soil water-holding capacity from each plot. Both could be obtained for future analyses. Further dynamics of water use and assimilation can be seen in table 20.

All surviving Fort Rock plot 16 stand conditions are expected to remain healthy, this is in contrast to the neighboring plot 10. *Armillaria* root rot would not be expected on plot 16 because the site is too dry (McDonald 1991).

Table 20—Summary of TREEBGC runs over the Julian days of 1 through 365 of old-growth and replacement stands for Fort Rock plot 16 on the Deschutes National Forest for the dry year of 1945 and the wet year of 1986

Situation	Stomate closure	Soil water	Gross PSN	Water use	All RESPIR	Net biomass	WUE
	Julian day	m3/ha	kg/m2	kg C/ha	kg C/ha	kg C/ha	g/g h2O
Old wet o	230+	356	5435	188.6	3101	.4668	.0025
Old dry o	230	135	3989	164.8	2483	.3012	.0018
Old wet	220+	338	4894	179.2	3028	.3732	.0021
Old dry	220	127	3679	155.6	2406	.2546	.0016
2nd wet85	180	109	5459	248	7258	-.3598	-.0015
2nd dry85	170	130	2511	188.3	6262	-.7502	-.0040
2nd wet37	210+	298	5322	188.1	3392	.3860	.0021
2nd dry37	210	116	3649	165.5	2635	.2028	.0012

o = water holding capacity increased 6% as result of increased organic matter in soil profile under old-growth and lacking under regeneration.

+ = Water-use efficiency. See footnote to table 19.

FORT ROCK PLOT 16

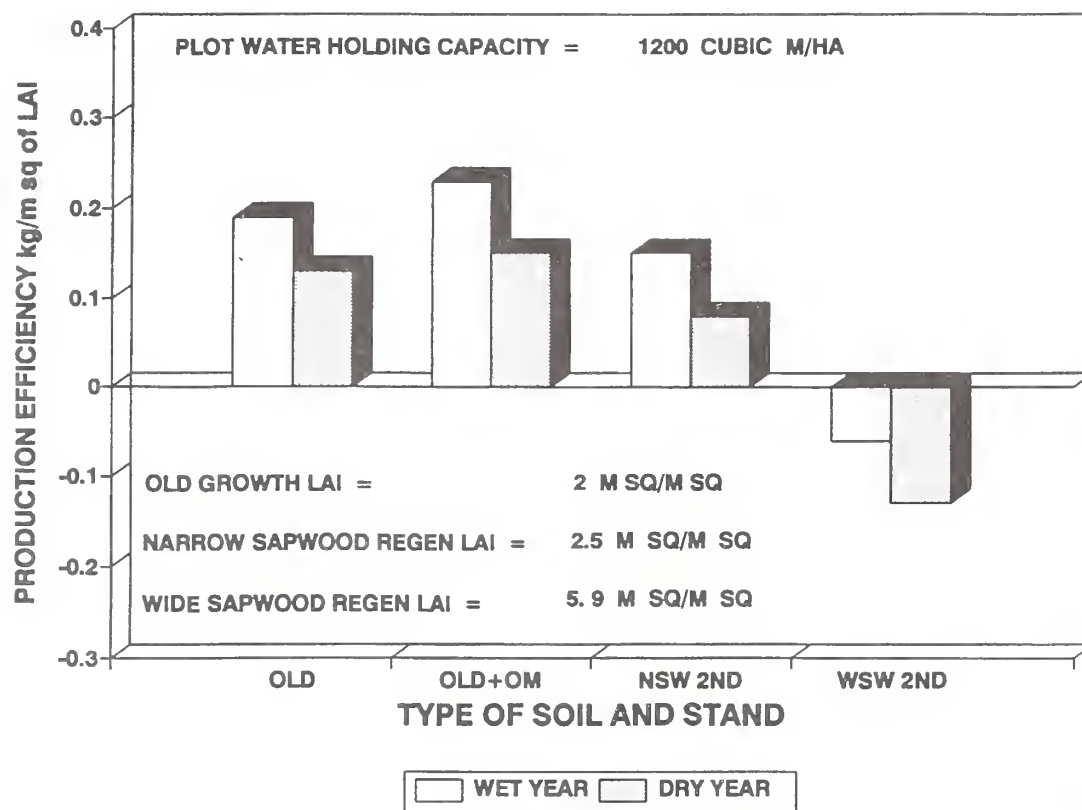


Figure 7. Production efficiency calculated from TREEBGC output after initialization by Fort Rock plot 16 old-growth and regeneration stand data and running on Wickiup Dam weather records for dry and wet years translated by MTCLIM and SNOWMELT weather models. Old + OM = old-growth stand data coupled with organic matter mediated increase in water holding capacity of 8 percent.

Moderate precipitation and moderate soil water-holding capacity—The two plots from Sugar Cast were similar (table 16). Both old-growth stands produced similar biomass. The reproduction stands were also alike but different from the old-growth (table 16). Thus, only plot 1 was analyzed. The old-growth seemed closer to using available water. An 8 percent increase in the water-holding capacity resulted in 1.5 times in the production efficiency of the old-growth for the wet years and erased a carbon deficit for the dry year (fig. 8). Production efficiency of the narrow-sapwood reproduction stand was near normal in the wet year and well into the positive range for the dry year. The reduced projected leaf area index for the narrow-sapwood regeneration probably signifies a problem with the run. Possibly the regeneration was thinned or its actual %SW closer to 50.

SUGAR CAST PLOT 1

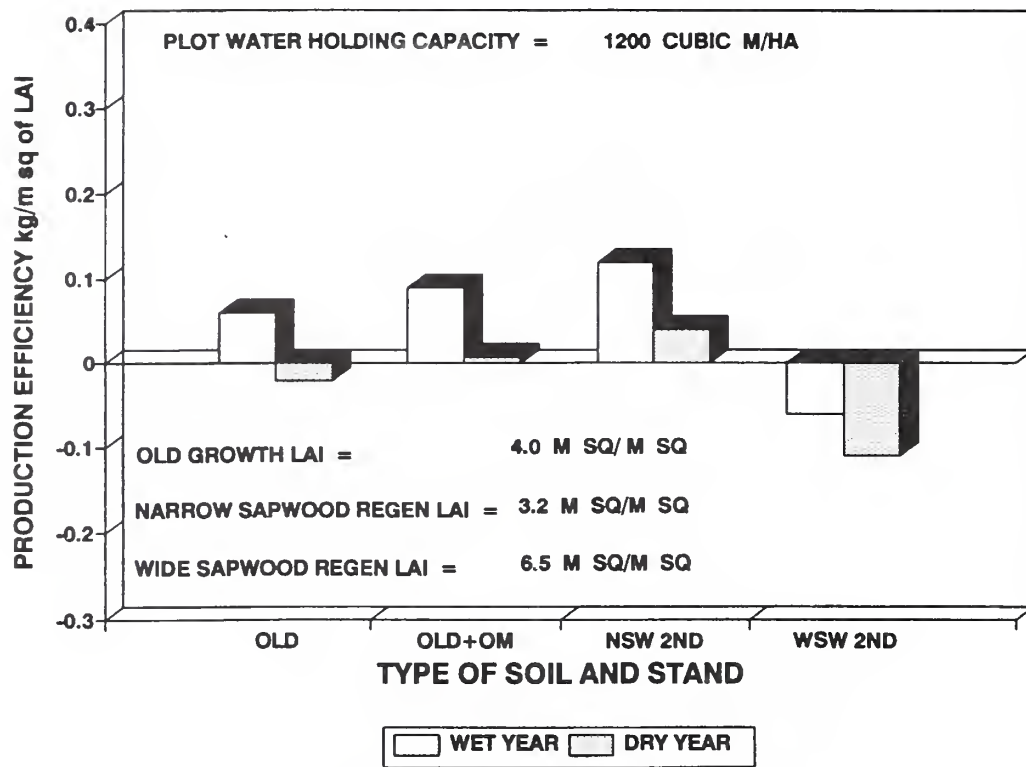


Figure 8. Production efficiency calculated from TREEBGC output after initialization by sugar cast plot 1 old-growth and regeneration stand data and running on Wickiup Dam weather records for dry and wet years translated by MTCLIM and SNOWMELT weather models. Old + OM = old-growth stand data coupled with organic matter mediated increase in water holding capacity of 10 percent.

Old-growth and reproduction close to carbon deficit show a problem with current use of TREEBGC. Measurements of such constants as B(11) through B(21) (appendix A) that deal with setting the physiology of water use, photosynthesis, and respiration (see table 21 for model output) are not available. Estimates for ponderosa pine growing in Montana were applied (Running and Coughlan 1988). To the extent these values apply, our results show the old-growth Sugar Cast stand was on a downward trend and reproduction at 49 years of age had not reached stability limits. The reproduction is expected to reach such a limit at about 1.5 to 2 times the equilibrium value for the leaf area index of 4.0. The wide-sapwood reproduction was already 1.6 times higher than that of old-growth (fig. 8), and the model indicates it is not suited for the site. This stand is water limited, as were both Fort Rock stands, and without additional water-holding capacity, other resources would not help. In a dry year, the snow melt was 1.4 times and rain was 1.6 times than the capacity of the soil to hold water (table 18). Enhancing water-holding capacity should be a principal management objective.

Even though this plot seems to have high production potential, during dry years the premanagement stand entered a period of risk for bark beetles. The model indicates that slightly increased water capacity would reduce this risk. This plot is also not subject to *Armillaria* attack because it is too dry (McDonald 1991).

Table 21—Summary of TREEBGC runs over the Julian days of 1 through 365 of old-growth and replacement stands for Sugar Cast plot 1 on the Deschutes National Forest for the dry year of 1945 and the wet year of 1986

Situation	Stomate closure	Soil water	Water use	Gross PSN	All RESPIR	Net biomass	WUE
	Julian day	m3/ha	kg/m2	kg C/ha	kg C/ha	kg C/ha	g/g h2O
old wet o	210+	306	260.3	6710	4924	.3572	.0014
old dry o	200	122	210.2	4032	3872	.0320	.0002
old wet	200+	289	248	5947	4779	.2336	.0009
old dry	190	127	197.8	3597	3941	-.0688	-.0003
2nd wet85	180	113	302	5857	7972	-.4230	-.0014
2nd dry85	180	115	240.8	3292	6884	-.7184	-.0030
2nd wet37SW	210+	300	226.8	6057	4130	.3854	.0017
2nd dry37SW	200	118	179.8	3661	3063	.1196	.0007

o = water holding capacity increased 8% as result of increased organic matter in soil profile under old-growth and lacking under regeneration.

+ Physiological activity stopped at indicated Julian day but resumed later.

High precipitation and moderate soil water-holding capacity—The Bend Ranger District represents sites with high precipitation and moderate soil water-holding capacity; BRD I and Q have different old-growth biomass measurements (table 16). The average age for all 19 plots was 40 years (Cochran and Hopkins 1991).

The TREEBGC runs indicated that the old-growth stand on plot I was in good balance with its environment (table 23 and fig. 10). Increasing water-holding capacity 15 percent, to simulate more organic matter only increased the production efficiency slightly for either wet or dry years, indicating the old-growth was well balanced. Also, production efficiency was near 0.1 even in the dry year. The stand was well buffered and, as shown by high soil water content remaining at Julian day 310 (table 22), was probably not water limited. This stand may be limited by some other resource, such as N. TREEBGC will be useful in the future for analysis of N relations.

Table 22—Summary of TREEBGC runs over the Julian days of 1 through 365 of old-growth and replacement stands for Bend Ranger District plot I on the Deschutes National Forest for the dry year of 1945 and the wet year of 1986

Situation	Stomate closure	Soil water	Water use	Gross PSN	All RESPIR	Net biomass	WUE
	Julian day	m3/ha	kg/m2	kg C/ha	kg C/ha	kg C/ha	g/g h2O
old wet o	310	720	507.9	13144	7309	1.1670	.0023
old dry o	240	170	331.5	7848	5323	.5050	.0015
old wet	310	666	490.4	12719	5537	1.1074	.0023
old dry	230	151	310.5	7068	5166	.3804	.0012
2nd wet85	310	644	462.3	12186	6718	.9246	.0020
2nd dry85	230	151	293.8	7035	4815	.4440	.0015
2nd wet37	310	762	349.3	10046	5047	.9998	.0029
2nd dry37	310	470	241.3	6511	3596	.5830	.0024

o = water holding capacity increased 15% as result of increased organic matter in soil profile under old-growth and lacking under regeneration.

Both sapwood widths showed excellent performance on plot I, with narrow sapwood looking best (fig. 9). This stand might have been thinned. The premanagement ponderosa pine was and is doing as well as the postmanagement stand. Dry white fir climax sites have shown a significant tendency toward root rot in encroaching white fir and Douglas-fir in the northern Rocky Mountains (McDonald and others 1987). Perhaps TREEBGC parameterized for these species would show a tendency toward stress. All stand scenarios on plot I seem well protected from pest problems because of vigorous growth.

BEND RANGER DISTRICT PLOT I

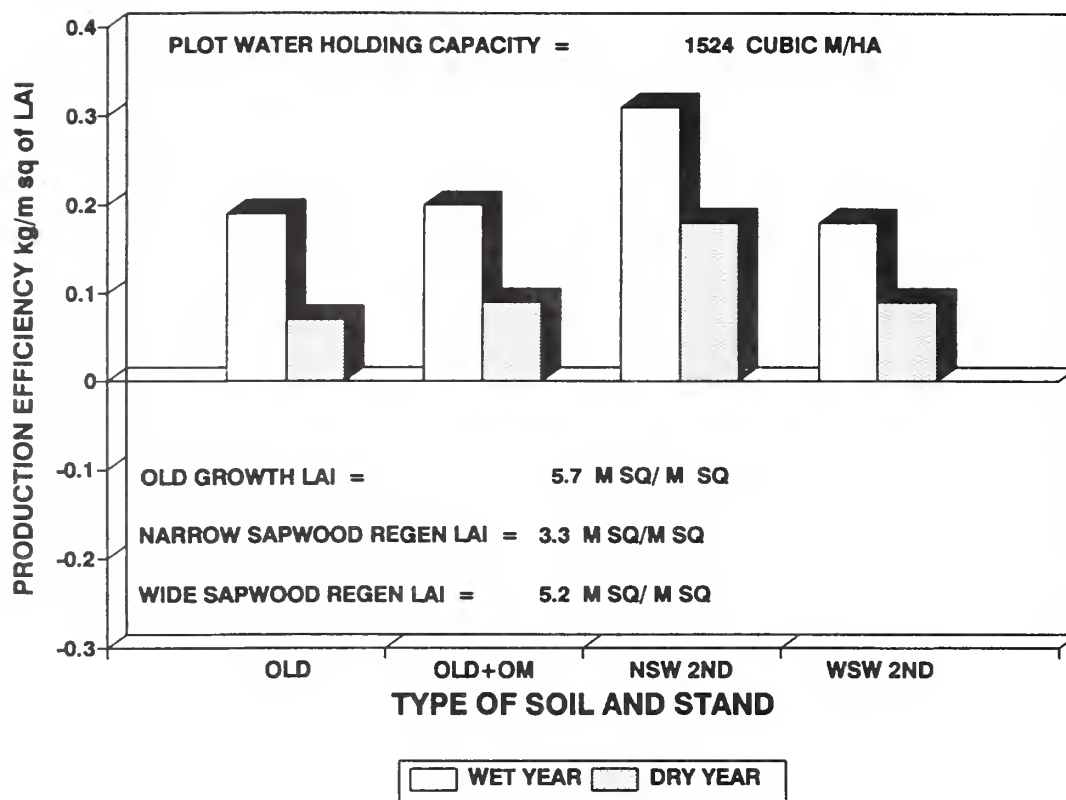


Figure 9. Production efficiency calculated from TREEBGC output after initialization by Bend Ranger District plot I old-growth and regeneration stand data and running on Wickiup Dam weather records for dry and wet years translated by MTCLIM and SNOWMELT weather models. Old + OM = old-growth stand data coupled with organic matter mediated increase in water holding capacity of 15 percent.

BRD-Q was an unusual plot because of the large calculated leaf area, 26.5 percent of its old-growth component. Theory indicates this value would be the expected equilibrium leaf area index. The regeneration stand should support leaf area indices of 40 to 50 LAI for 20 to 30 years, depending on current age. With a current cover of 47 percent, BRD-Q might achieve that goal; the old-growth stand was near the balance point. Under the assumption of 15 percent increased soil water capacity, the stand produced a net carbon gain, even during the dry year (table 23). For average water condition, BRD-Q was very close to balance and had only a slightly negative production efficiency for the dry year (fig. 10), indicating that plot Q had sufficient resources other than precipitation and that this stand would come under frequent stress if organic matter was depleted. This old-growth stand was probably N limited.

Table 23—Summary of TREEBGC runs over the Julian days of 1 through 365 of old-growth and replacement stands for Bend Ranger District plot Q on the Deschutes National Forest for the dry year of 1945 and the wet year of 1986

Situation	Stomate closure	Soil water	Water use	Gross PSN	All RESPIR	Net biomass	WUE
	Julian day	m3/ha	kg/m2	kg C/ha	kg C/ha	kg C/ha	g/g h2O
old wet o	220+	660	737.5	13861	10417	.8368	.0011
old dry o	210	179	449	7915	7750	.0330	.0001
old wet	220+	611	719.6	13805	10191	.8222	.0011
old dry	210	142	429.8	7579	7808	-.0458	.0001
2nd wet85	310	621	479.4	12360	1501	1.0780	.0022
2nd dry85	230	141	303.9	7136	4976	.4320	.0014
2nd wet37	310	787	329.9	9469	4690	.9558	.0029
2nd dry37	300	175	230.5	6228	3362	.4610	.0020

o = water-holding capacity increased 15 percent as result of increased organic matter in soil profile under old-growth and lacking under regeneration.

+ Physiological activity stopped at indicated Julian day but resumed later.

The premanagement stand on this plot may include trees at elevated risk to bark beetles and *Armillaria*, although the regeneration appeared well protected by vigorous growth. Grand fir and Douglas-fir, however, would be at risk to root rot.

The regeneration stand for BRD-Q showed the most growth potential of any stand with either wide or narrow sapwood. Its narrow sapwood production efficiency was over 0.3 kg/m² (fig. 10), yet the modeled water-use efficiency was 0.0029 g biomass / g H₂O, a value measured for Douglas-fir seedlings (Livingston and Black 1988). None of the four BRD regeneration stands were stressed by limited water, even in the dry year. Their production efficiency for the dry year was almost equal to the next best plot (Fort Rock 16, old wet + organic matter, fig. 7) in a wet year. These stands were not limited by water when supporting ponderosa pine.

BEND RANGER DISTRICT PLOT Q

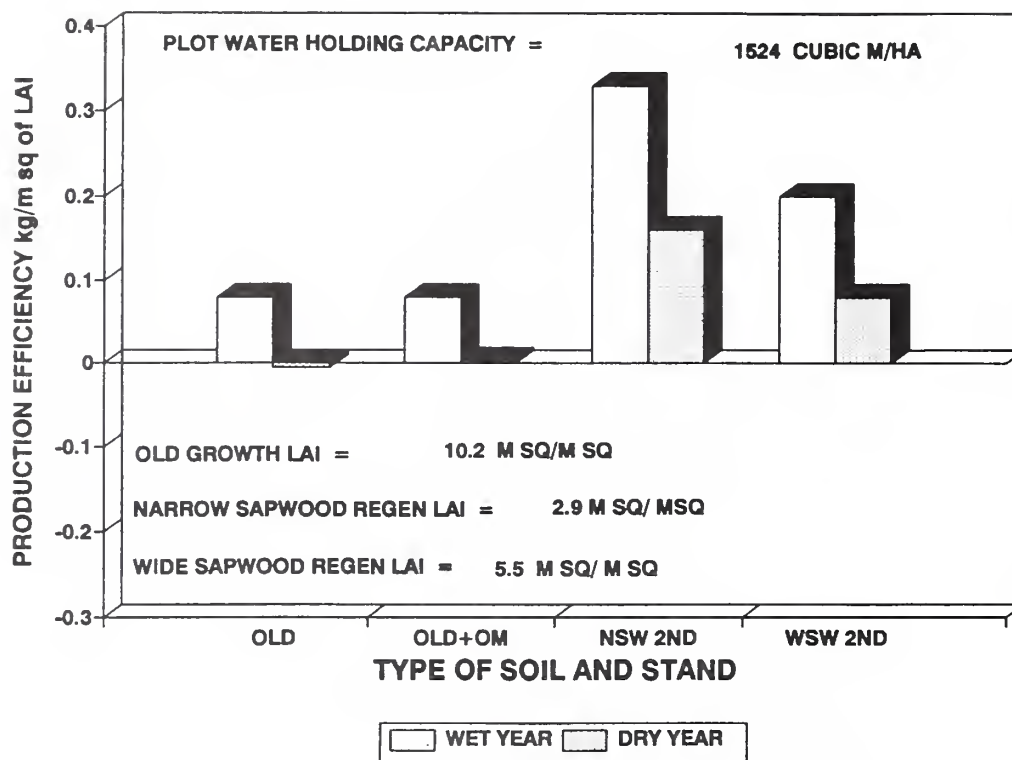


Figure 10. Production efficiency calculated from TREEBGC output after initialization by Bend Ranger District plot Q old-growth and regeneration stand data and running on Wickiup Dam weather records for dry and wet years translated by MTCLIM and SNOWMELT weather models. Old + OM = old-growth stand data coupled with organic matter mediated increase in water holding capacity of 15 percent.

Eastside Perspectives

Properly initialized and verified individual-tree process models, coupled with tested and calibrated climate models, could supply powerful analytical perspectives. This model exercise demonstrates that potential. "Potential" is emphasized because the suite of models used were not calibrated and verified for the Deschutes National Forest. MTCLIM and TREEBGC have been verified to provide reasonable results in Montana (Hunt and others 1991, McLeod and Running 1988, Nemani and Running 1989, Running and Nemani 1987). Snowmelt was verified on watersheds supporting ponderosa pine in the southwest (Foltz 1987). But to obtain the most information from these models more data are needed. Also needed are sapwood percentages, the age of all trees, and local regressions of sapwood area to leaf area. These models also depend on accurately estimating maintenance respiration in various tissues, N concentration and good local determinations of specific leaf area. Other data needed include actual site soil water-holding capacity and N content. Even without all the best initialization parameters, application of these models produced very reasonable results and a rich set of analytical perspectives.

SUMMARY AND CONCLUSIONS

Soil structure, porosity, and nutrient capital are attributes of ecosystems least tolerant of actions during or after timber harvest. Harvest can initiate sudden shifts in forest ecosystem dynamics. Distribution of moisture and solar energy may change radically, altering soil and air temperatures and evapotranspiration rates at the soil surface and within the remaining canopy. Site degradation can be caused by excessive soil

compaction, which is often coupled with the loss of surface soil containing a disproportionately high percentage of the soil organic matter, nutrient capital, and water-holding capacity. Silvicultural and harvest prescriptions should be specific to the capacities and sensitivities of the site, soil, and desired vegetation. Recovery times are too long and possible remedies too costly to justify management alternatives that permit significant soil degradation (Cochran and Brock 1985, Froehlich 1979, Froehlich and McNabb 1984, Froehlich and others 1985, Geist and others 1989, Graecen and Sands 1980, Harvey and others 1987, Jurgensen and others 1990, Sullivan 1988).

Managing eastside vegetation systems to balance them with soil and climatic characteristics requires considerable understanding of local- and ecosystem-scale characteristics. Generalized approaches will require site-specific modifications, and not all methodologies will be suitable for every site. Site-analysis methodologies to balance water and nutrient stores with vegetation-use rates will be important for maintaining long-term productivity and for regulating pest activities at both the stand and ecosystem scale. Fertilizer and other ameliorative or growth enhancing treatments will be required.

Fire Effects

Fire plays a natural and important role in balancing vegetation systems with site, soil and climate. This role includes recycling stored carbon and nutrients back to the soil, which, in turn, regulates moisture storage capacity. Management methods can meet these requirements, but prescribed fire and wildfire must be kept within historical norms, or with in prescribed ameliorative treatments. Historical norms likely included some highly destructive events. Proper management can prevent such destruction by emphasizing fire control and fuel management on those sites most at risk. Until effective analytical procedures are in more general use, we recommend that fire intensities always be kept in the low to moderate range if possible; we fully recognizing that intense wildfires cannot always be prevented and that they have occurred in the past. Most important, as with other forest disturbances and management actions, soil organic matter losses should be kept at a minimum. When prescribed burning is indicated, the forest floor should be moist. Proactive fuel management should be an integral part of all silvicultural operations.

Harvesting System Effects

Harvesting systems range from conventional hand-felling coupled with ground-based skidders (tracked or wheeled vehicles offering little or no log suspension), to high lead cable (one-end log suspension), loader line and carriage sets (full-log suspension or nearly so), to sky-line or balloon and helicopter (full-log suspension). The use of ground-based mechanical harvesters is increasing because of their speed of operation, maneuverability, and lower labor costs. These harvesters include feller-bunchers that travel to each tree (these cut and stack whole trees for ground skidders) and “cut-to-length” machines that operate on specified or chosen accessways. These last machines have an articulated arm with an end that can cut, delimb, section, and stack logs of prescribed length. Stacks are picked up and transported to landings by machines called forwarders. Both kinds of harvesters have been used in commercial thinning and final harvest operations in eastern Washington and Oregon.

Ground-based systems are more commonly used on slopes of 30 percent or less and often result in the highest vegetation and soil disturbance (mostly soil compaction and displacement). Disturbance grades downward from common ground-skidding to high lead, to skyline, and finally to balloon or helicopter removal systems (Dyrness 1965, Klock 1975). Removal costs generally rise in the same progression. Where units have reach-out arms, mechanical harvesters have been purported to cause less disturbance than conventional skidding because they stay on specified trails and travel on logging slash. In theory, this practice should significantly reduce the area and degree of compaction, displacement, and erosion, but the validity of such claims remains largely unsubstantiated. One problem in eastside forests may be that the amount of slash is too light to adequately cushion trails.

Even-Aged, Uneven-Aged, and No-Management Effects

Most public forestry agencies have shifted from even-aged to uneven-aged management, primarily because of the public perception that uneven-aged management is less damaging to the environment, better for wildlife, and will result in a more aesthetically pleasing landscape. Many forest structural attributes are retained with uneven-aged management, because fewer trees are cut at one time in a given area; silvicultural operations such as weeding and thinning, however, are necessary to allow reasonable growth rates for replacement trees.

With uneven-aged management, the potential for soil damage increases because, with fewer trees removed over larger areas, ground-based extraction to avoid excessive cost is mandatory. With this forest management approach the probability of excessive soil damage threatens long-term wood production. Short- and long-term growth reductions from traffic-induced soil compaction and soil displacement are expected, with poor inducements to remedy either. No “final removal” of the stand is made in uneven-aged management, and costs of remedying compaction are unlikely to be covered under the decreased return per unit area. Where dedicated access routes are used for harvest, growth loss needs to be evaluated for acceptability.

A “no management” approach is problematic and provides few options for either increased recreational use or managed production. Over time, no management is likely to result in increasingly unnatural pressures on the ecosystem without any means of relief and little opportunity would exist for mid-course corrections of potential ecosystem crises.

Productivity and Sustainability Under Management

Guidelines for the appropriate management of forest soils are not easily defined, because of the spatial complexity of soil and its variability both within and among sites. Management of soil resources can be characterized within a conservation strategy.

For the following definition, “productivity” is a baseline of acceptable biological growth measured under prescribed conditions and “sustainability” is the perpetuation of a desired ecosystem, including the functional soil processes that regulate the system. To maintain ecosystem productivity and sustainability, soil quality must be maintained. Targeted goals for soil maintenance may be defined in terms of several attributes (for example, organic matter, nutrients, water-holding capacity, bulk density), depending on knowledge about the particular ecosystem. A soil attribute might also be co-defined by parallel changes in one or more biological parameters, such as mycorrhizal activities or N-fixation rates. Conservation strategies can be expressed in rather simple terms, but real world applications are often complex. For example, sustaining vigorous vegetation growth requires manipulation as water and nutrient supplies change over time.

The Current Soil Management Strategy

In National Forests of the Pacific Northwest Region, the Forest Service has set soil conservation standards. These standards might be considered thresholds that affect productivity and sustainability. They stipulate that, for example, detrimental conditions shall not exceed 20 percent of an area, including allowance for roads. Because roads commonly are about 5 percent, this translates to about 15 percent for an actual treatment area (Meurisse 1988).

The Forest Service defines detrimental conditions as:

Compaction—an increase in bulk density of 15 percent or more over the normal background mineral soils, other than those derived from volcanic ash or pumice (in those soils, compaction is an increase in bulk density of 20 percent or more);

Puddling—depth of rutting in tracks is 6 inches or more; and

Displacement, removal, or both—the loss (mechanical or fire) of 50 percent or more of the topsoil or humus-enriched A1 and AC horizons, or both, from an area of 100 square feet or more, which is at least 5 feet wide (Meurisse 1988).

With these standards in mind, the authors would summarize their soil management concerns with the following warnings:

1. Keep the soil in place by minimizing or avoiding soil erosion and mechanical soil displacement, whether from natural or human-caused events.
2. Minimize influences that cause excessive areas and degrees of soil compaction.
3. Minimize loss of soil organic matter.

Soil and the Forest Health Issue

Insofar as soil bulk density, water, organic matter, and N storage regulate the amounts, types, and physiological condition of any vegetation that an ecosystems can support, they are pivotal to health problems. Other soil-related factors, such as selected nutrient or microbial characteristics may also be important to a lesser degree. Changes in stand densities and species distribution through fire exclusion, harvesting history, or both may restrict natural processes that balance aboveground vegetation with belowground resources. Without fire, the ecosystem must compensate by accelerating biological decomposition through recycling and mortality processes, including insect and disease activity—a process that assures that fire will eventually return to the system. Appropriate restoration of that balance, and prevention of soil degradation, will be prerequisite to returning forest health to premanagement levels.

Weather-Stand-Soil Interactions

The modeling exercise shows that evaluating relative risk requires something more than a casual analysis of site, soil, and vegetation. For some stand-soil-climate situations, adding or subtracting even small amounts of soil organic matter may greatly affect growth potential or pest risk. Yet, for other situations, even large increases in available water may have no effect. Retrospective climate evaluation with temperature and moisture measurements over a 95-year period showed that climatic factors are not likely to have been directly involved in recent forest health changes. Site modeling analysis of the type demonstrated should be highly useful in evaluating the likelihood of forest health problems.

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APPENDIX A

Physical constants used in MTCLIM and SNOWMELT models

Description	Model	Value
Site albedo	MTCLIM	0.15
Sea level atmospheric transmissivity	MTCLIM	0.65
Sea level atmospheric transmissivity	SNOWMELT	0.20
Temperature lapse rate	MTCLIM	6.4 (C/1000m)
Lapse rate for maximum temperature	MTCLIM	8.2 (C/1000m)
Lapse rate for minimum temperature	MTCLIM	6.0 (C/1000m)
Dew lapse rate	MTCLIM	2.7 (C/1000m)
Potential evapotranspiration	SNOWMELT	12 values ¹
Maximum cover density of snow shaded	SNOWMELT	% cover/plot
Fraction of snow actually shaded	SNOWMELT	% cover/plot
Threshold temperature for reflectivity	SNOWMELT	32°F
Initial calorie deficient of snowpack	SNOWMELT	-1 calorie
Caloric input or loss from pack/day	SNOWMELT	10 calories
Free water in snowpack	SNOWMELT	0
Snow on trees	SNOWMELT	0
Water equivalent in snowpack	SNOWMELT	0 inches
Recharge deficit for soil	SNOWMELT	0
Temperature at top of snowpack	SNOWMELT	32°F
Temperature at middle of snowpack	SNOWMELT	32°F
Temperature at bottom of snowpack	SNOWMELT	32°F
Base station temperature rain to snow	SNOWMELT	32°F

¹ Monthly potential ET January through December in inches/day 0.001, 0.001, 0.03, 0.16, 0.22, 0.32, 0.3, 0.38, 0.15, 0.1, 0.015, 0.001 determined as function of monthly average radiation and air temperature (Campbell 1977).

APPENDIX A (continued)

Biological and physical constants used to initialize the individualized forest process model TREEBCG

Value	Description		
1	KSTART = START SIMULATION LOOP COUNTER		
366	STOP = STOP SIMULATION LOOP, DAY		
1	DAY OUTPUT CONTROL: 1 MEANS YES; 0 MEANS NO		
1	GRW OUTPUT CONTROL: 1 MEANS YES; 0 MEANS NO		
0	LNG OUTPUT CONTROL: 1 MEANS YES; 0 MEANS NO		
0	TREE OUTPUT CONTROL: 1 MEANS YES; 0 MEANS NO		
10	KPRINT = IF 10 THEN DAY OUTPUT ONCE EVERY 10 ITERATIONS		
1	YIELD TABLE = IF 1 THEN YIELD OUTPUT ONCE EACH YEAR		
0	KBEGIN = BEGIN PRINTING AFTER ITERATION > KBEGIN		
365	LOOP = LOOP TO THE CARBON/NIT SUBMODEL EVERY xx DAYS		
0	LIFE CYCLE REDEFINE B CONSTANTS WITH LOOP # (1= YES, 0=NO, *.LIF FILE)		
0	SEASONALLY REDEFINE B CONSTANTS WITH YEARDAY (1= YES, 0=NO, #.SEA FILE)		
0	NEGX = PRINT ERROR MESSAGES WHEN X(I) IS NEGATIVE: 1 MEANS YES.		
29	NUMX = NUMBER OF X VALUES TO READ		
833 P*	X (1)	SNOWPACK	(M**3) *
650 P**	X (2)	SOIL WATER CONTENT	(M**3)**
0.0	X (3)	WATER OUTFLOW	(M**3)
0.0	X (4)	TRANSPIRATION	(M**3)
0.0	X (5)	EVAPORATION	(M**3)
0.0	X (6)	PSN	(KG)
0.0	X (7)	RESPIRATION AUTOTROPHIC	(KG)
1715 P	X (8)	LEAF CARBON	(KG)
36938 P	X (9)	STEM CARBON	(KG)
1715 P	X (10)	ROOT CARBON	(KG)
3000	X (11)	LEAF/ROOT LITTER CARBON	(KG)
000	X (12)	RESPIRATION DECOMP, C	(KG)
40000	X (13)	SOIL CARBON	(KG)
25	X (14)	AVAILABLE NITROGEN	(KG)
25.7	X (15)	LEAF NITROGEN (1.5% OF X8)	(KG)
100	X (16)	STEM NITROGEN	(KG)
16	X (17)	ROOT NITROGEN (.75% OF X10)	(KG)

APPENDIX A (continued)

300	X (18)	L/R LITTER NITROGEN (1% OF X11)	(KG)
3000	X (19)	SOIL NITROGEN	(KG)
000	X (20)	NITROGEN LOSS	(KG)
0.0	X (21)	LEAF MORTALITY LOSS	(KG)
0.0	X (22)	STEM MORTALITY LOSS	(KG)
0.0	X (23)	ROOT MORTALITY LOSS	(KG)
16.5 P	X (24)	AVERAGE MID-CROWN HT	(m)
1608 P	X (25)	PLOT SIZE	(M**2)
11.6 P	X (26)	RESPIRATION SURFACE	(M**3)
43.20 P	X (27)	AVE DBH - STAND LEVEL (cm) ONLY NEEDED IF	
20.9 P	X (28)	AVE HT - STAND LEVEL (m) NOT USING TREE LIST	
119 P	X (29)	STAND DENSITY	(tree/ha)
51	Numb=	NUMBER OF B CONSTANTS TO READ	
25	B (1)	SPECIFIC LEAF AREA	(M**2/KG C)
-0.5	B (2)	CANOPY LIGHT EXTINCTION COEFFICIENT	
650 P	B (3)	SOIL WATER CAPACITY	(M**3)
0.0005	B (4)	INTERCEPTION COEFF	(M/LAI/DAY)
10000	B (5)	GROUND SURFACE AREA	(M**2/HA)
0.0007	B (6)	SNOWMELT COEFF	(M/DEG C/DAY)
44	B (7)	LATITUDE	(DEG)
0.8	B (8)	1 - SURFACE ALBEDO	
0.5	B (9)	SPRING MIN. PMS	(MPA)
3000	B (10)	RAD. RED LC THRESHOLD	(KJ/M**2/DAY)
0.0016	B (11)	MAX CANOPY AVG. LC	(M/SEC)
2.0	B (12)	LWP AT STOMATAL CLOSURE	(MAP)
0.045	B (13)	SLOPE ABS HD REDUCTION	(M/SEC/ABSHD)
432	B (14)	PSN LIGHT COMP PT.	(KJ/M**2/DAY)
9720	B (15)	PSN I	(KJ/M**2/DAY)
0.0008	B (16)	MAX LC (C02)	(M/SEC)
7.5	B (17)	MIN TEMP. PSN	(DEG C)
37	B (18)	MAX TEMP. PSN	(DEG C)
0 0001	B (19)	LEAF RESPIRATION COEFF	
0.00007	B (20)	STEM RESPIRATION COEFF	
0.00017	B (21)	ROOT RESPIRATION COEFF	
10	B (22)	SAPWOOD TURNOVER (YEARS)	
4.0	B (23)	TEMP. EFFECT MESOPHYLL COND. ADJUSTMENT COEFFICIENT	

APPENDIX A (continued)

50.0	B (24)	DECOMPOSITION TEMPERATURE OPTIMUM	
0.085	B (25)	Q10=2.3 CONSTANT FOR EXPONENTIAL RESPIRATION SURFACE	
0.044	B (26)	MAXIMUM CAN AVE LEAF NITROGEN CONC	(% x 2.2 C/CH2O)
0.0132	B (27)	MINIMUM CAN AVE LEAF NITROGEN CONC	
0.80	B (28)	MAX LEAF NITROGEN RETRANSLOCATION FRACTION (DIM)	
0.03	B (29)	SOIL/LITTER DECOMPOSITION RATE FRACTION (DIM)	
0.5	B (30)	N/C DECOMP RELEASE FRACTION (DIM)	
26.5	B (31)	MAXIMUM LEAF AREA INDEX, ALL SIDES (DIM)	
6.0	B (32)	LEAF TURNOVER RATE (YR)	
0.25	B (33)	LEAF LIGNIN FRACTION (%/100)	
1.0	B (34)	SOIL WATER LEAF/ROOT ALLOCATION FACTOR (DIM)	
1.0	B (35)	NITROGEN AVAIL LEAF/ROOT ALLOCATION FACTOR (DIM)	
0	B (36)	DATE OF SPRING LEAF GROWTH (YEARDAY)	
365	B (37)	DATE OF FALL LEAF CROP (YEARDAY)	
20.0	B (38)	MOBILE N RETENTION TIME (YR)	
2.5	B (39)	ATMOSPHERIC DEPOSITION N (KG/HA/YR)	
5.0	B (40)	BIOLOGICAL FIXATION N (KG/HA/YR)	
0.00	B (41)	STEM TURNOVER COEFF	
0.80	B (42)	ROOT TURNOVER COEFF	
0.35	B (43)	LEAF GROWTH RESP	
0.30	B (44)	STEM GROWTH RESP	
0.35	B (45)	ROOT GROWTH RESP	
50	B (46)	DECOMPOSITION TEMPERATURE OPT (DEG)	
0.03	B (47)	SOIL/LITTER C DECOMP FRACTION (DIM)	
0.4	B (48)	DECOMPOSITION RATE SCALAR (DIM)	
225.0	B (49)	STEM CONVERSION FACTOR FROM VOLUME TO CARBON	
0.25	B (50)	LEAF CONVERSION FACTOR FROM SAPWOOD AREA TO LEAF AREA	
0.5	B (51)	K = LEAF SHADING COEFFICIENT	
0	NUMIZP=	NUMBER OF Z VARIABLES TO PRINT:	CAN BE 0
0	NUMIGP=	NUMBER OF G VALUES TO PRINT:	CAN BE 0

* Value used here was determined by subtracting value given by TREEBGC snowpack from SNOWMELT value. TREEBGC constantly underestimated the result obtained from the more sophisticated SNOWMELT model.

** In this case, soil water-holding capacity for Fort Rock 10 (610 M3/ha) was increased 6 percent to simulate increased capacity under old-growth (D. Page-Dumroese, pers. comm.).

P Indicates value changes for each run.

APPENDIX B

Model calibration: Regression equations, their r^2 s and standard errors are as follows.

Old Growth Volume for all plots in cubic feet:

$$\ln(\text{ft}^3) = -6.657 + 1.9307\ln\text{Dbh} + 1.1633\ln\text{H}$$

Where:

Dbh = diameter breast height in inches

H = height in feet

$r^2 = .99$, standard error 0.14.

Old Growth Dbh as function of the diameter outside bark of a 20-inch stump

$$\text{Fort Rock Dbh} = -0.679 + 0.8982\text{DS} \quad r^2 = 0.97 \text{ se} = 0.78 \text{ in}$$

$$\text{Sugar Cast Dbh} = -0.8208 + 0.9134\text{DS} \quad r^2 = 0.97 \text{ se} = 0.78 \text{ in}$$

$$\text{Bend R D Dbh} = -0.1988 + 0.8998\text{DS} \quad r^2 = 0.98 \text{ se} = 0.72 \text{ in}$$

Old Growth Height (H) as a function of DBH:

$$\text{Fort Rock } \ln\text{H} = 4.8137 - 9.3759/\text{Dbh} \quad r^2 = 0.47 \text{ se} = 0.09$$

$$\text{Sugar Cast } \ln\text{H} = 4.8492 - 7.3156/\text{Dbh} \quad r^2 = 0.40 \text{ se} = 0.08$$

$$\text{Bend R D } \ln\text{H} = 5.035 - 11.746/\text{Dbh} \quad r^2 = 0.44 \text{ se} = 0.09$$

Stem Carbon (ST):

$$\text{ST}_p = \text{VOL}_i * 225$$

Where:

VOL_{ip} = volume of the ith individual summed over the pth plot.

225 = conversion of wood from volume to carbon

All-sided Leaf Area (LA):

$$\text{LA}_i = \text{BA}_i / 0.0001 * \% \text{SW}_i * 0.25 * 2.6$$

Where:

LA_i = all-sided leaf area of the ith tree in m^2

BA_i = basal area of ith tree in m^2

0.0001 = conversion of basal area to cm^2

$\% \text{SW}_i$ = percent of basal area that is sapwood of the ith tree

0.25 = conversion from sapwood basal area to 1-sided leaf area of ith tree

2.6 = conversion from 1-sided leaf area to all-sided leaf area of the ith tree

Leaf Carbon for plot (LCp):

$$\text{LC}_p = \text{sum } \text{LA}_i / 25$$

Where:

$\text{sum } \text{LA}_i$ = Leaf area of ith trees on pth plot

25 = specific leaf area in m^2/kg carbon

All-sided Leaf Area Index for plot (LAI):

$$\text{LAI}_p = \text{sum } \text{LA}_i / \text{PA}$$

Where:

PA = area of plot over which LA was summed.

Total Plot Respiration Surface volume (RS) (from R. Korol):

$$\text{RS} = \text{SWV}_i + \text{SV}_i$$

Where:

SWV = sapwood volume of ith tree

= volume of ith tree * $\% \text{SW}$ * 0.1 (assume 0.1 living cells)

SV_i = surface volume of ith tree

= $\text{VOLA}_i - \text{VOLD}_i$

VOLA_i = living surface volume = $(3.1416 * r^2 * H) / 3$

VOLD_i = dead surface volume = $(3.1416 * dr^2 * H) / 3$

APPENDIX B (continued)

Where:

$$r = Dbh_i/2 * 0.01$$

H_i = Height of ith tree

$$dr = r - 0.005 \text{ (assumes bark 0.5 cm thick)}$$

Sapwood Area regression (Hunt and others, 1991):

$$S = (-0.27 + 0.835d)^2$$

Where:

S = sapwood area in cm^2

d = diameter at 1.3 M in cm

Individual Old-Growth Crown Coverage (Moeu, 1981):

$$\ln(CW) = 1.62365 + 1.08137\ln(D) - 0.68098\ln(H) + 0.29786\ln(CL)$$

Where:

CW_i = diameter of ith tree crown in feet

D = diameter at breast height in inches

H = height of tree in feet

CL = length of crown in feet (assumed for open grown ponderosa pine old-growth to be 50% of height)

and Crown Cover for plot (CC):

$$CC = \text{sum of } ((CW_i/2) * 3.1416 * 0.0929) / \text{plot area}$$

Managing for Featured, Threatened, Endangered,
and Sensitive Species and Unique Habitats for
Ecosystem Sustainability

by

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and Gonzalo C. Castillo

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ABSTRACT

The traditional approach to wildlife management has focused on single species—historically game species and more recently threatened and endangered species. Several newer approaches to managing for multiple species and biological diversity include managing coarse filters, ecological indicator species, indicator guilds, and use of species-habitat matrices. These and other modeling approaches each have strong points as well as weak points, which include conflicts among objectives for species with disparate needs. We present three case examples of integrating management for single species with management for multiple species and ecosystems. These examples are: managing elk habitat in the Blue Mountains of eastern Oregon; managing for sustainable native fish faunas in eastern Oregon and Washington; and managing plant and animal species closely associated with old-growth forests in the Pacific Northwest. Each case illustrates a unique set of considerations and ecological conditions. Successful integration of species and ecosystem management depends on clearly defining objectives at several scales of time and space, and not violating the three most basic principles of ecosystem management: maintaining or restoring biodiversity, maintaining long-term site productivity, and maintaining sustainable use of renewable resources.

INTRODUCTION

Biological diversity has been described as the variety of life and its processes (Keystone Center 1991). Managing for biological diversity on lands administered by USDA Forest Service includes species management. Species-specific management of plants and animals is a traditional approach focusing both on amount, distribution, and quality of habitat, as well as key environmental factors such as food, cover, and water (Leopold 1933). The single-species orientation has included managing a sustainable, harvestable surplus of fish and wildlife game species; maintaining habitat for featured species and management indicator species; protecting sensitive and State-designated rare species; and recovery of Federally designated threatened and endangered species.

In recent years, however, other aspects of biological diversity have been recognized as natural resources worth conserving (Hansen and others 1991, SAF 1991). These include unique, scarce, and declining habitats, such as old-growth forests and riparian vegetation not disturbed by human activities, and entire plant and animal communities and ecosystems. Traditional approaches, however, which focus on individual species and their habitats might inadequately provide for these new management objectives (Noss 1991, Thomas and others 1993).

As a result, a new management paradigm has emerged within the USDA Forest Service, focusing now as much on biological diversity and ecological processes as on individual species. Within this context of ecosystem management, three main themes are appearing: maintaining and restoring biological diversity (including conserving species, populations, genomes, and communities); maintaining long-term site productivity; and maintaining long-term sustainability of use of renewable natural resources. These three themes collectively encompass and surpass (but should not supersede) the traditional species focus for management. Conflicts in site-specific management objectives have arisen in early attempts to merge these broader goals with those of the traditional species-specific approach.

In this paper, we discuss some of the recent methods proposed for species management within the larger context of ecosystem management of biological diversity. We explore some potential conflicts and propose resolutions. Next, we present three case studies of integrating species-specific management objectives into an ecosystem framework. We conclude with general recommendations for integrating the species focus with broader ecosystem management objectives. This paper focuses on managing biological resources; economic and other resources will require additional consideration.

METHODS FOR INTEGRATING SPECIES AND ECOSYSTEM MANAGEMENT

The challenge forest managers face today is to manage threatened, endangered, indicator, featured, game, and sensitive species in a context that also conserves biological diversity, site productivity, and sustainability of resource use. In this section, we discuss some of the proposed approaches: coarse-filter and fine-filter species management, ecological indicator species, indicator guilds, and use of species-habitat matrices.

Coarse-Filter and Fine-Filter Species Management

Coarse-filter species management (Hunter 1990, 1991; The Nature Conservancy 1982; Noss 1987) assumes that conserving land areas and representative habitats, such as old forests or streamside zones, will provide for the needs of all associated species, communities, environments, and ecological processes. In contrast, a fine-filtered approach specifically provides for only the habitats, substrates, and conditions for a single or few species. An example is the Forest Service's management requirements for pileated woodpecker (*Dryocopus pileatus*).

The efficacy of a coarse-filter approach has seldom been tested. An example is the coarse-filter management program proposed by The Nature Conservancy (1982), which has estimated that 85 to 90 percent of target species would occur within their representative ecosystems.

Another example of testing a coarse-filter approach is the viability assessment of plant and animal species associated with old-growth forests of Washington and Oregon in the range of the northern spotted owl (*Strix occidentalis caurina*), as conducted by Thomas and others (1993). They demonstrated that, to ensure protection of the complete old-growth forest community, a coarse-filter approach to conserving old growth would still have to consider a wide variety of rare and locally endemic species and other species of the upland forests at a species-specific scale. Their evaluation demonstrated that the fine-filter approach to managing habitat for the northern spotted owl would provide for only about a third of all plants and animals closely associated with old-growth forests within the owl's range in National Forests. Hence, the conclusion is that, to ensure conservation of the entire old-growth community, a combination of both coarse-filter management for single species fine-filter management for multiple species would be needed. Additional details of this case are discussed below.

The coarse-filter approach is appealing in its cost savings. However, assumptions that a complete community or assemblage of plants or animals would be provided needs to be evaluated on a case-specific basis.

Related to the coarse-filter approach is the use of umbrella or flagship species, which are usually large, charismatic birds or mammals with broad distributions or area needs. The working assumption—seldom tested, and likely not often valid—is that managing habitats for umbrella or flagship species adequately provides for the host of all other species found in those habitats. One example of the flagship-species approach is management of forest reserves for tigers (*Panthera tigris*) in India.

Managing With Ecological Indicator Species

Another approach to multiple-species management is through the use of ecological indicator species. An ecological indicator species is one whose presence, distribution, and population trend is assumed to index those of other species associated with a common geographic area or habitat. The more effective indicator species chosen for management have narrow tolerances to environmental conditions; such species readily respond to changes in those conditions.

The USDA Forest Service uses ecological indicator species to simplify developing and implementing management guidelines (Sidle and Suring 1986). The indicator species concept was originally developed to

evaluate how the vitality of a particular species—commonly, but not always, a plant—reflects the overall trophic health of its environment. Examples of using indicator species for management include: assessing richness of algae species as an index to the degree of aquatic eutrophication (Nygaard 1949); lichen species indicating continuity and overall health of conifer forests (Tibell 1992); vascular plants correlating with condition of pastureland in Great Britain (Helliwell 1978); presence and abundance of litter spiders indexing forest recovery after clearcutting (McIver and others 1990); and tiger beetles indexing overall biological diversity (Pearson and Cassola 1992). Other examples are found in the literature.

In recent years, however, much doubt has been cast on the assumption that any forest vertebrate species can adequately indicate the specific population size and trend of other vertebrate species (Landres and others 1988, Morrison and others 1992, Patton 1987). This use of ecological indicator species typically fails because each species has its own unique niche and distinctive response to environmental conditions, and differs from other species in morphology, behavior, resources used, competitive interactions, and other biological and ecological characteristics (Morrison and others 1992). Moreover, coincidence in population size or trend between two or more species does not necessarily lead to an understanding of the cause. This is problematic if the indicators are used to test management standards. Discerning whether species are responding to the same conditions as the indicator species is impossible.

Ecological indicator species are but one type of “management indicator,” that is, a quantifiable property of an environment that correlates with desirable conditions (for example, Hunsaker and others 1990). Management indicators other than ecological indicator species are legitimate and useful tools for tracking and predicting environmental conditions and trends, such as for ecosystem recovery (Kelly and Harwell 1990) or for management of biodiversity (Noss 1990, Williams and Marcot 1991). Some of these tools are described below.

Managing With Indicator Guilds

An approach related to that of ecological indicator species is that of using species guilds to simplify assessing effects or devising management standards (Hunter 1990). In this approach, a guild of species having similar ecological characteristics is treated as a group. Guilds may be composed of ecologically similar species from very diverse taxa. For example, some rodents, birds, and ants may be within one guild of seed-eating species. The assumption—seldom tested and likely not often valid—is that all species of the guild will respond similarly to changes in environmental conditions.

Morrison and others (1992) evaluated such a “guild indicator” approach to species management of forest birds. They concluded that fundamental ecological differences between species of a guild typically resulted in individual species responding differently—sometimes with opposite numerical responses—to environmental conditions. Thus, to be reliable, a guild indicator approach to multiple-species management requires case-specific empirical testing.

Managing With Species-Habitat Matrices

Another approach to multiple-species management is the use of species-habitat matrices. Species-habitat matrices depict the relative quality of vegetation associations and seral stages for various life needs, typically for reproduction, feeding, and resting or cover. Also depicted is information on use of sundry vegetation substrates and components, such as snags and down wood and logs. One of the original species-habitat matrices was developed for eastern Washington and Oregon (Thomas 1979). This early work led to the formation of the Wildlife-Habitat Relationships Program within the USDA Forest Service, including creation of species-habitat matrices among other regions and ecological provinces (Salwasser and others 1980).

Species-habitat matrices have been used in forest planning to help identify forest types, conditions, and seral stages, and special habitats—such as cliffs, caves, lakes and ponds, riparian vegetation, snags and wildlife trees, and down logs—for managing multiple species of wildlife (Patton 1992, Toth and others 1986). Validation studies of these matrix models (Dedon and others 1986, Laymon 1990, Raphael and Marcot 1986), however, have demonstrated that their most effective use is for forest planning over the

scale of watersheds and landscapes, rather than for predicting individual population responses to stand-scale conditions and changes.

Managing With Other Modeling Approaches

Other approaches to assessment and management of multiple species include models of habitat and population response. For example, Hansen and others (1990) modeled responses of wildlife habitats to management and to change in climate. This habitat response model could then be used in conjunction with information on species-habitat relationships to predict trends in vertebrate community composition over broad areas, such as was predicted from empirical studies of terrestrial vertebrates in northwestern California (Raphael and others 1988, Raphael and Marcot 1989).

In a mathematical approach, Hof and Raphael (in press) developed an optimization model for predicting the most equitable combination of habitats (forest types and their seral stages) that would meet management objectives for multiple species simultaneously. In a similar but qualitative approach, Toth and others (1986) used species-habitat matrices to develop schematics of forest habitat patch layout patterns that would meet the needs of multiple species requiring two or more kinds of habitats.

Still other population and habitat modeling approaches include: habitat capability and suitability index models; habitat evaluation procedures; Bayesian and pattern recognition models; models of optimal foraging; population viability models; wildlife community structure models; and models of vegetation structure, stand growth, and forest succession. Attributes and examples of these models were reviewed by Morrison and others (1992).

This brief summary of a few of the more popular approaches to multiple-species assessment and management underscores our conclusion that no short cut to evaluating species' responses and requirements exists. Instead, the traditional species focus needs to be continued but must be integrated into an ecosystem context as our knowledge and tools for analysis become more sophisticated.

Further Considerations for Managing Species and Unique Habitats

Several National Forests have integrated management for multiple species combining the most stringent requirements among a set of species. For example, the Tahoe National Forest in California (Chapel and others 1992) and Tongass National Forest in Alaska (Samson and others 1989) developed management recommendations for conserving old-growth forests for wildlife. In the Pacific Northwest, similar old growth management recommendations were developed for threatened species, species deemed to be at risk of extirpation, and groups of species sharing similar ecologies. This last example, which identified management needs incrementally, is discussed below.

Management of unique habitats can entail a different approach that includes mapping the location and extent of the habitat and superimposing proposed management activities to identify areas of potential conflict. Also, by use of area analysis or cumulative effects analysis, the effects of off-site and previous management activities can be identified, mapped, and evaluated to help determine how they influence conservation of desired habitat conditions on site. This entails the use of area analysis or cumulative effects analysis.

Another consideration in management for species and unique habitats is the effect of such management on the sustainability and productivity of the land for other organisms and objectives. For example, protection of large forest stands from timber harvest, silvicultural manipulation, and fire control might induce higher risks of insect outbreaks and stand-replacing fires. This is especially true if such stands had previously been protected from natural fires and, as a result, changed in composition or accumulated a high fuel volume. Emphasis on management for single objectives that ignores either fire hazards or the need for a natural fire regime might adversely influence future ecological conditions. A good knowledge of distur-

bance dynamics of each ecosystem is needed. Such knowledge can be gained from reconstructing historical locations, frequencies, and intensities of disturbances such as fires and outbreaks of forest insects. Historical fire atlases, and retrospective studies on past vegetation conditions and disturbance dynamics, are two tools that will be in greater demand under a broader ecosystem management approach.

Management alternatives that affect plant and animal species have been traditionally considered in local contexts only. Management practices commonly have been implemented at stand and subdrainage scales without explicit consideration of broader areas. Recently, however, the Forest Service has begun to conduct hierarchical analyses in space and time to assess the collective needs of plant, fish, and terrestrial wildlife populations and species. They are now bringing together, over large spatial scales and long time frames, each of the essential components of landscapes, watersheds, basins, and regions that collectively meet the long-term habitat requirements of featured, threatened, and other species. They have only begun to evaluate ecosystem diversity, productivity, and sustainability.

In this spirit, nested scales of space and time should be considered when assessing effects, when defining management objectives and desired future conditions, and when developing mitigations and management standards and guidelines. In a dynamic forest ecosystem and landscape, desired future conditions are not necessarily a single, static state; rather, they can be expressed as a span of conditions. For example, Caraher and others (1992) described a range of natural conditions of various attributes of the Blue Mountains in northeastern Oregon.

In this type of analysis, a major factor is the potential for conflicts among simultaneous management objectives. For example, consider an approach to optimize and balance the needs of multiple objectives, such as for featured, game, rare, sensitive, threatened, or endangered species. Some game species require early successional vegetation. For example, black-tailed deer (*Odocoileus hemionus*) require shrub openings close to hiding cover. And hunters require road and trail access to the deer. In the same general landscape, another species might require a very different condition. As examples, *Brotherella roellii*, a rare species of moss, is closely associated with old-growth and closed canopy conditions in the Pacific Northwest. Although not an old-growth obligate, wolverines (*Gulo gulo*) and grizzly bears (*Ursus horribilis*) require large roadless tracts. Thus, landscape and vegetation conditions that would maximize one species might be antithetical for conservation of another. Only by considering all needs and objectives at the onset can habitat requirements of multiple species be optimized. Examples of conflicting objectives and a resolution method are discussed below.

More often than not, when managing for multiple species and ecosystems, we are faced with a dearth of information on environmental conditions and species' life histories, ecologies, and population status. Although developing management guidelines under such conditions is possible, we emphasize the need for basic information, particularly value- and resource-free inventories and classifications of ecological conditions. In the Pacific Northwest, much information is needed on status, trends, and habitat relationships of many plant and animal species. Such information can be gathered through basic research, inventory, and monitoring programs, and evaluated for use in an adaptive management framework.

Additional management considerations are outside the scope of this paper and include social, political, and economic effects, as well as effects on abiotic resources, such as water quality, visual resources, air quality, and roads.

INTEGRATING SPECIES AND ECOSYSTEM MANAGEMENT: THREE CASE STUDIES

We offer three examples of integrating management for species with management for ecosystems: managing elk (*Cervus elaphus*) in the Blue Mountains of eastern Washington and Oregon, managing fish species and stocks in eastern Washington and Oregon, and managing plant and animal species closely associated with old-growth forests in western Washington, Oregon, and California. The purpose of presenting these examples is to show that solutions to ecosystem and multiple-species management are typically case-specific and no one approach applies to all. Despite differences in methods, the objectives among these examples are similar and attempt to maintain species viability and ecosystem health, productivity, diversity, and sustainability.

Example 1: Managing for Elk in the Blue Mountains of Eastern Oregon

In this example, we apply principles of landscape ecology to managing diverse wildlife guilds. The setting for this example is the Blue Mountains Province of northeastern Oregon and southeastern Washington. Our intent is to stimulate new paradigms for wildlife and ecosystem management. To this end, we demonstrate a hypothetical method to evaluate landscapes in a holistic manner, for a featured species and some dissimilar wildlife guilds. We also discuss landscape designs to accommodate these divergent needs.

Our example uses species and guilds composed of large mammals and birds because their life requisites are better known than those of most amphibians, reptiles, and small mammals. Consequently, our discussion and example apply to the spatial scales commensurate with the home ranges and dispersal distances of large vertebrates, typically areas of subwatershed and watershed scales. Subwatersheds in the Blue Mountains generally range from 1000 to 10,000 acres. Watersheds, as aggregates of subwatersheds, generally range from 10,000 to 50,000 acres.

However, for a complete analysis of wildlife use of landscapes, smaller spatial scale evaluations, such as of an individual tree, snag, log, or vegetation stand, also are required. These scales are especially important when considering the needs of small mammals, amphibians, reptiles, and some resident birds, which often have substantially smaller home ranges than do large mammals and other birds. In our example, however, we do not discuss the effects of individual sites and stand structures per se. Rather, we focus on the effects of vegetation patch sizes and arrangements at scales of the subwatershed and watershed. Such an analysis should be considered a complement to stand-scale management.

Historical elk management: emphasis on game species—Wildlife managers have traditionally emphasized the production of game species for consumption. Management usually focused on producing a single species for a single user group. Nongame species, without benefit of a strong constituency, often were given little attention. Moreover, the ecological role and effect of game management rarely was addressed in the context of a functioning ecosystem.

In North America, many game species use two or more distinct types of habitat to meet life requisites. These “multitype” species benefit from close proximity of different seral stages (Thomas and others 1979). Hence, wildlife managers often have advocated fragmenting habitat patches of different seral stages to maintain a high edge effect. Their intent was to maintain two or more desired habitats, each representing a distinct seral or structural stage, close to one another to meet multiple-habitat requisites within the species’ home range (Thomas and others 1979).

Leopold’s *Game Management* (1933) reflected this approach. Leopold developed his law of interspersion (1933:129-132) at a time when wildlife management was just emerging as a science in North America. He

was the first scientist to use edge effect as a popular concept (also see Lay 1938). Although it has been recently challenged (Harris 1988, Reese and Ratti 1988), this paradigm remains a popular and ecologically sound approach for managing multitype or edge-associated species (Guthery and Bingham 1992).

Examples of multitype species in the Blue Mountains include elk, wild turkey (*Meleagris gallapavo*), blue grouse (*Dendragapus obscurus*), mountain bluebird (*Sialia currucoides*), northern flicker (*Colaptes auratus*), great horned owl (*Bubo virginianus*), and great gray owl (*Strix nebulosa*). Such species benefit from interspersions of habitat patches, along with a useful ecotone between the patches (Guthery and Bingham 1992). In general, the useful ecotone is the edge that occurs between young and old forest seral stages or between grassland and forest, referred to as “high contrast edge” by Thomas and others (1979). Edges between mid-seral and old forests, for example, likely are not used by these multitype species as frequently as are edges between young and old forests (Thomas and others 1979).

A myriad of other wildlife species do not benefit from, and often are adversely affected by, high interspersions or fragmentation of habitat patches (Harris and Silva-Lopez 1992, Morrison and others 1992). These “unitype” or habitat-interior species are associated primarily with one seral or structural stage. (The categories of unitype and multitype species is a simplification for management purposes; it is difficult to categorize some species as either type.) Examples of habitat-interior species in the Pacific Northwest have been identified in field research studies by Hansen and others (1990), Lehmkuhl (1990), Lehmkuhl and others (1991), Lehmkuhl and Ruggiero (1991), Marcot (1985), and Rosenberg and Raphael (1986). These studies identified various species associated with large or interior conditions of forest stands (such as varied thrush (*Ixoreus naevius*), Hansen and others 1990) or clearcuts (such as western wood peewee (*Contopus sordidulus*), Marcot 1985). Such species generally respond negatively to a high contrast edge between young and old seral stages; they persist optimally in large habitat patches that contain minimal edge and maximal interior. In general, as the area of interior habitat increases, so does the likelihood of occurrence and persistence of unitype species associated with the patch (Morrison and others 1992).

Persistence of unitype species also depends on the connectivity of like habitat patches across the landscape. In general, the shorter the distance between and among like patches, the higher the probability of sufficient connectivity to maintain adequate population size. Adequate population size is defined as that needed to withstand stochastic declines in breeding, dispersal, and survival that threaten a species’ persistence at defined spatial and temporal scales.

Much attention has been given to landscape designs that minimize fragmentation and enhance connectivity of old forest patches (Franklin and Forman 1987, Lamberson and others 1992). Examples of species likely to benefit from such designs in the Blue Mountains include northern goshawk (*Accipiter gentilis*), Townsend’s warbler (*Dendroica coronata*), pileated woodpecker (*Dryocopus pileatus*), black-backed woodpecker (*Picoides articus*), Vaux’s swift (*Chaetura vauxi*), northern flying squirrel (*Glaucomys sabrinus*), and American marten (*Martes americana*).

Other unitype species may persist in large habitat patches of early seral stages (Hansen and others 1990, Marcot 1985). Examples in the Blue Mountains include mourning dove (*Zenaida macroura*), chipping sparrow (*Spizella passerina*), American goldfinch (*Carduelis tristis*), Brewer’s blackbird (*Euphagus cyanocephalus*), Columbian ground squirrel (*Spermophilus columbianus*), and northern pocket gopher (*Thomomys talpoides*).

Few if any unitype species in the Blue Mountains seem to be closely associated with mid-seral forest stages. The sharp-shinned hawk (*Accipiter striatus*) appears to come closest; it makes extensive use of mid-seral forests but also forages in both young and old forests. Thus, it is more a multitype species than a unitype species.

Landscape relationships of elk and unitype species—How are landscapes used by dissimilar guilds, especially when one species is “featured,” perhaps to the detriment of others? If we knew the answer, we

might understand a bit more about ecosystem management for wildlife. We attempt here to describe how landscapes of the Blue Mountains are used by a featured species in relation to wildlife guilds that have highly dissimilar needs.

We chose elk as the featured species because it is designated as “featured” by nearly every National Forest in which it occurs, including those of the Blue Mountains. We contrast this species’ predicted patterns of use with those of unitype or habitat-interior species for three distinct landscapes. Ecological relationships that form the basis for this evaluation are described as follows (also see table 1).

Elk: a multitype species—Elk is an edge-associated species that responds positively to increasing fragmentation of seral stages (Thomas and others 1988, Wisdom and others 1986). Landscape management of elk involves two complementary strategies: manipulating their spatial and temporal distribution through effective land treatments; and controlling their population size and manipulating their sex and age composition (population structure) through effective harvest regimes.

The first strategy, commonly referred to as “elk habitat effectiveness,” is defined by Lyon and Christensen (1992:4) as the “percentage of available habitat that is usable by elk outside the hunting season.” This percentage is a gross index of the ability of land managers to “grow elk” and influence their distribution.

The second strategy, coined as “elk vulnerability,” is defined as “the susceptibility of elk to being killed during the hunting season” (Lyon and Christensen 1992:3). Elk vulnerability pertains to the ability of population managers to manipulate the number and population structure of elk through hunting (Thomas 1991).

Models of habitat effectiveness predict the relative distribution of elk within and among habitat patches by subwatershed. Predictions are based on elk response to the interspersion and quality of habitat patches and to the density of roads. Thomas and others (1988) developed a habitat effectiveness model for elk winter ranges in the Blue Mountains that predicts elk distribution based on four variables: size and spacing of forage and cover patches; density of roads open to motorized traffic; quality of cover patches; and quantity and quality of forage (table 1).

Table 1--Descriptive effects of landscape changes on elk and unitype species within subwatersheds of the Blue Mountains

Landscape Changes	<u>Elk</u>		<u>Unitype Species</u>	
	HE[1]	ES[2]	Young Forest	Old Forest
Increasing fragmentation or edge effect	Positive[3]	Negative	Negative	Negative
Increasing road density and human uses	Negative[4]	Negative	Negative	Negative
Increasing size and connectivity of old forest patches	Variable[5]	Positive	Negative	Positive
Increasing size and connectivity of young forest patches	Variable[6]	Negative	Positive	Negative

[1] Habitat Effectiveness

[2] Elk survival during hunting season; Negative = low survival or high vulnerability to harvest; Positive = high survival or low vulnerability to harvest

[3] Increases HE related to size and spacing of habitats (HEs)

[4] Decreases HE related to density of open roads (HEr)

[5] Increases HE related to cover quality (HEc); decreases HE related to size and spacing (HEs)

[6] May increase HE related to forage quantity and quality (HEf); decreases HE related to size and spacing (HEs)

Models of elk vulnerability are under development. The variables thought to significantly increase elk vulnerability to harvest include: high density of hunters, high density of roads, loss or absence of large cover patches, and gentle terrain (Thomas 1991). Effects of these and other variables on elk harvest are shown in tables 1 and 2.

Table 2--Landscape problems that increase elk vulnerability to harvest and the corresponding landscape remedies (from Thomas 1991:319)

<u>Landscape Problems</u>	<u>Landscape Remedies</u>
1. Increasing density of roads	1. Design roads to minimize effects. Close roads permanently or temporarily. Enforce road closures
2. Increasing density of hunters	2. Restrict hunter numbers
3. Decreasing amounts of cover	3. Control stand configuration, juxtaposition, and size through modifications in timber management program
4. Fragmenting of cover into smaller patches	4. Retain adequate escape cover in the form of stands of several hundred or more acres
5. No restriction on antler class in bull harvest	5. Impose regulations on what can be taken -- such as allowing the kill of spike antlered bulls only
6. Setting of open seasons that include the rutting period	6. Ensure that open seasons do not include the rutting period.
7. Improving technology	7. Preclude "modern" weapons
8. Long open seasons	8. Shorten the open season
9. Relatively gentle terrain	9. Decrease road density, maintain more cover, increase size of cover patches, decrease hunter numbers
10. Increasing number of hunter days	10. Related to both items 2 and 8 above. Reduce hunter numbers or reduce length of hunting season, or both

Unitype species associated with old forests—Many species in the Blue Mountains are associated with old (late-successional, including mature and old-growth) forests. Few data exist, however, about specific responses of these species to changes in patch size, amount, and arrangement. We therefore borrow principles of landscape ecology derived from other provinces and regions for our discussion here.

In general, the occurrence and persistence of species associated with old forest patches increases with increasing patch size and connectivity of such patches, as described earlier and as summarized by Morrison and others (1992). Moreover, microclimate inside old forest patches is modified with increasing distance from openings. For example, Chen and others (1992), working in southern Washington and central Oregon, found evidence that extremes in microclimate were partially or fully modified within interior portions of forest patches of old-growth Douglas-fir (*Pseudotsuga menziesii*) that exceeded 150 yards from openings (young forests). Also, susceptibility to windthrow likely decreases with increasing size and interior portions of old forest patches.

Moderation of thermal environment and reduction in windthrow along edges are confounded by physiography (Chen and others 1992). For example, an old forest patch exposed on a ridgetop and surrounded by young forests likely is more susceptible to windthrow and is subject to greater extremes in weather than a similar patch downslope. The relations described above are generally predictable (table 1) but require local adjustment to account for effects of physiography.

Unitype species associated with young forests—In contrast to species associated with old forests, even fewer data are available about the response of young forest-associated species to landscape change. This subject has been largely ignored by researchers of landscape ecology. Working in young-growth Douglas-fir in northwestern California, Marcot (1985) found that, on average, 25 percent of the variance in bird abundance that was not explained by site conditions was explained by landscape attributes. Such attributes included slope angle, slope position, distance to nearest permanent water, distance to next nearest similar habitat, habitat patch size, and number of different edges (adjacent stands). For example, during the breeding season, variation in abundance of western wood pewees, warbling vireos (*Vireo gilvus*), and western tanagers (*Piranga ludoviciana*) was accounted for by proximity to the next nearest shrub patch. During the winter season, chestnut-backed chickadees (*Parus rufescens*), cedar waxwings

(*Bombycilla cedrorum*), and evening grosbeaks (*Coccothraustes vespertinus*) exhibited this pattern. However, the majority (71 percent) of the 91 bird species observed showed no correlations with landscape attributes. Autecological studies are needed to better determine landscape relationships of species associated closely with young seral stages.

Although data are scant, it is logical to assume that unitive species associated with young forests respond similarly to patch size and arrangement of their selected habitats, as do unities that use old forests. That is, species occurrence and persistence can be expected to increase with increasing size and connectivity of desired patches (table 1).

Landscape distribution of elk and unitive species—Both multitype and unitive species appear to respond to a common attribute: distance from edge between young and old forests. Hence, this attribute can be used to evaluate the probability of species or guild use of habitat patches within a subwatershed. (Other attributes could be similarly evaluated.) Predicted use can be described in terms of a relative probability distribution, which is defined as the relative proportion of time or area that a habitat patch is used by a species or guild. Probability distributions of use of distance bands from edges can be scaled from 0.0 to 1.0, where 1.0 represents 100 percent probability of use by a species or guild relative to other areas having probabilities less than 100 percent. Similarly, 0.0 is equal to 0 percent probability that a particular area is used. The sum of all probabilities within a subwatershed, weighted by area, equals the composite, relative probability of species or guild use for the subwatershed as a whole.

Thomas and others (1988) defined elk use of habitat patches in this manner. Their size and spacing variable described a probability distribution for elk by 100-yard distance bands from edges, into both forage and cover areas in a given subwatershed (table 3). Thomas and others (1988) defined forage areas as patches with an overhead canopy closure of 40 percent or less. They defined cover areas as patches with an overhead canopy closure exceeding 40 percent. They further classified cover into two types: marginal cover, which are patches with overstory canopy closure of 41 to 69 percent having overstory trees 10 to 39 feet tall; and satisfactory cover, which are patches with 70 percent overhead canopy closure and overstory trees 40 feet tall or taller.

Table 3--Hypothetical probability distributions of elk and unitive species in relation to distance from edge between young, mid-seral and old forest patches

Distance from edge [1] (yards) Into young forest (elk forage areas)Relative probability distribution.....		
	Elk	Young forest species	Old forest species
0 - 100	1.00	0.25	0.00
100 - 200	0.54	0.50	0.00
201 - 300	0.54	1.00	0.00
301 - 500	0.14	1.00	0.00
> 500	0.04	1.00	0.00
Into mid-seral forest (elk marginal cover)			
0 - 100	1.00	0.00	0.125
101 - 200	0.14	0.00	0.25
201 - 300	0.14	0.00	0.50
> 300	0.005	0.00	0.50
Into old forest (elk satisfactory cover)			
0 - 100	1.00	0.00	0.25
101 - 200	0.14	0.00	0.50
01 - 300	0.14	0.00	1.00
> 300	0.005	0.00	1.00

[1] Edges are defined as the ecotone between young and mid-seral forests, and the ecotone between young and old forests.

We used these definitions to determine that forage areas are analogous to young forests, marginal cover is analogous to mid-seral forests, and satisfactory cover is analogous to old forests. Meaningful edge is the ecotone between forage areas and marginal or satisfactory cover, but not between marginal and satisfactory cover (Thomas and others 1988).

These concepts can also be applied to unitype species. What follows must be considered a working management hypothesis that requires rigorous testing and validation. We present this hypothesis as a first attempt to implement landscape evaluation and management of unitype wildlife guilds. It is not a tool to predict absolute probabilities of species occurrence or persistence. It may be useful, however, in estimating the relative “fitness” of subwatersheds for these guilds, and in demonstrating the relative likelihood of guild use within and among habitat patches. (Also, the caveats given above—that species within indicator guilds often display disparate numerical responses to environmental conditions—also should be tested for this example.) The following five assumptions form the basis of our working management hypothesis:

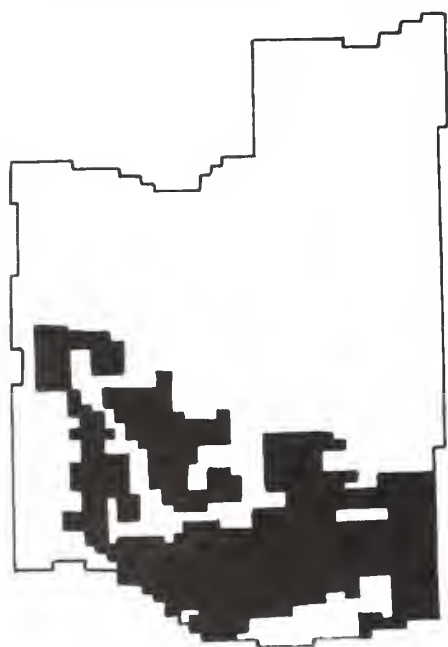
- ❑ Assumption 1: Unitype species distribute themselves positively and incrementally away from meaningful edge. Meaningful edge in the Blue Mountains is between young and old forests, or between young and mid-seral forests. Definitions of forage and cover areas for elk (Thomas and others 1988) can serve as interim descriptors of young versus mid-seral or old forest patches, respectively, until new research provides more specific definitions.
- ❑ Assumption 2: Unitype species that use old forests are distributed most positively (with a use index value of 1.0) in portions of old forest (elk satisfactory cover) that exceed 200 yards from an edge with young forest (elk forage areas). Mid-seral forest (elk marginal cover) is used by unitypes as well, but highest use is suboptimal (use index value of 0.5) to that of old forest. Areas of mid-seral or old forest over 200 yards from edges of young forests represent the interior portions of habitat that experience the least variation in microclimate and least susceptibility to windthrow. Also, habitat-interior species are more vulnerable to predation by edge-associated species with increasing proximity to edge (Harris and Silva-Gomez 1992). We assume that the distribution of old forest species thus declines linearly with increasing proximity to edge with young forest, with none of the young forest edge itself used (use index value of 0.0). Table 3 summarized these hypothesized probability distribution of use by 100-yard distance bands from meaningful edge into early-, mid-, and late-seral stages.
- ❑ Assumption 3: Unitype species closely associated with young forests are distributed most positively (use index value of 1.0) in portions of young forests greater than 200 yards from an edge with mid-seral or old forest. We hypothesize that the distribution of young forest species declines linearly with increasing proximity to edge with mid-seral or old forest, with none of the mid- and late-seral forest edge itself used (use index value of 0.0) (table 3).
- ❑ Assumption 4: Effect of variations in vegetative structure and composition on abundance of unitype species within and among habitat patches is not specifically addressed in this example and is assumed to not influence species distribution and abundance. These variations include individual structures such as snags, logs, and trees, as well as composition of overstory and understory woody and herbaceous vegetation. Response of Blue Mountains fauna to management of these stand-scale attributes has been addressed previously (Thomas 1979). Our hypothesis is designed as a complement to stand-scale management, not as a substitute. That is, we assume that stand-scale management of vegetation structure and composition for wildlife is already underway in the Blue Mountains. We further assume that unitype species respond to patch size and arrangement described here only if forest structures desired by such wildlife are well distributed across the associated patches and seral stages. If these stand-scale needs are not actively managed, our hypothesis is invalid.

- Assumption 5: We assume that our hypothesis is more applicable to subwatersheds under even-aged silvicultural forest management than to more complex stand structures resulting from uneven- or all-aged management. Even-aged silviculture typically results in seral stages that can be delineated and identified as distinct patches. By contrast, uneven-aged treatments often result in patches that contain elements of multiple seral stages; distinct patches (and edges) may not be evident. Effects of uneven-aged management on unitype guilds require more intensive evaluation at the stand scale, and responses of wildlife may be independent of patch size or arrangement.

Also, a comprehensive list of unitype species for ecosystems of the Blue Mountains is not available. Such a list should be developed as part of the research required to test this hypothesis.

Evaluating subwatersheds—Our hypothesis can be applied to ecosystems of the Blue Mountains to demonstrate the theoretical effects of subwatershed management on disparate wildlife guilds. We did so by applying the probability distributions in table 3 to three subwatersheds of the Umatilla National Forest. Subwatersheds were selected to reflect three distinct landscapes: subwatershed 1 is dominated by patches of large, relatively unfragmented young forests (fig. 1); subwatershed 2 contains patches of large, relatively unfragmented mid-seral and old forests (fig. 2); and subwatershed 3 is composed of highly fragmented patches of all seral stages (fig. 3).

Acreages of all seral stages within each 100-yard distance band away from edge in each of these three test subwatersheds were estimated by using a geographic information system and software developed by Hitchcock and Ager (1992). Summaries of the distance band analyses are shown in figures 1, 2, and 3.



Legend 1

Band	Young	Mid	Old
1-100	189.6	100.9	100.0
101-200	77.5	84.7	0.0
201-300	66.1	21.2	0.0
301-400	56.8	0.0	0.0
401-500	62.5	0.0	0.0
> 500	599.2	0.0	0.0
Total Acres 1358.5	1051.7	206.8	100.0

Figure 1. Subwatershed 1: 1358 acres, of which 1052 acres are young forest, 206 mid-seral, and 100 old forest. Young is light shading. Mid-seral and old are dark shading. Acreage within distance bands away from edges is shown in Legend 1 above.

The results (table 4) show dramatic differences in probability distributions of potential use by elk and unitype guilds among the three subwatersheds. As expected, subwatershed 1 provides the greatest probabilities of use by unitype species associated with young forests, and the lowest probabilities of use by old-forest species and elk. Subwatershed 2 provides a higher probability of potential use by old-forest species, yet a low probability of use by elk and by young-forest species. Subwatershed 3 provides the greatest probability of use by elk, but a low probability of use by both young- and old-forest species.



Legend 2

Band	Young	Mid	Old
1-100	178.2	92.5	171.5
101-200	23.2	72.3	148.2
201-300	1.0	28.9	125.5
301-400	0.0	11.4	97.1
401-500	0.0	7.7	92.5
> 500	0.0	11.9	238.1
Total Acres	202.5	224.7	872.9
1300.1	15.6%	17.3%	67.1%

Figure 2. Subwatershed 2: 1300 acres, of which 202 acres are young forest, 225 mid-seral, and 873 old forest. Young is light shading. Mid-seral and old are dark shading. Acreage within distance bands away from edges is shown in Legend 2 above.



Legend 3

Band	Young	Mid	Old
1-100	614.2	242.3	344.5
101-200	233.5	100.2	152.9
201-300	65.6	28.4	62.0
301-400	24.3	6.7	6.7
401-500	5.7	0.0	0.0
> 500	0.0	0.5	38.2
Total Acres	943.2	378.1	604.3
1925.6	49.0%	19.6%	31.4%

Figure 3. Subwatershed 3: 1926 acres, of which 943 acres are young forest, 378 mid-seral, and 604 old forest. Young is light shading. Mid-seral and old are dark shading. Acreage within distance bands away from edges is shown in Legend 3 above.

Application of this method shows its potential utility in ranking the relative condition of subwatersheds for dissimilar wildlife guilds. Such a tool, if validated by research, could provide managers with a new approach for managing for multiple species of wildlife. Specifically, it could be used to design patch size, amount, and arrangement to accommodate the needs of various wildlife guilds at the subwatershed scale. This method also could be useful for analyzing cumulative effects of timber sales and other silvicultural treatments within and among subwatersheds.

Table 4--Relative probability distributions of elk and unitive species for the 3 subwatersheds shown in figures 1, 2 and 3

Site	-----Relative probability distribution [1]-----		
	<u>Elk</u>	<u>Young forest</u>	<u>Old forest</u>
Subwatershed 1 (fig. 1)	0.39	0.64	0.05
Subwatershed 2 (fig. 2)	0.40	0.05	0.52
Subwatershed 3 (fig. 3)	0.74	0.19	0.18

[1] Calculations: Relative probability = [(area in distance band) x (probability distribution in distance band)] summed for all distance bands in all patches of a subwatershed.

At the subwatershed scale, this method accounts for the effects of amount, arrangement, size, and, to a limited degree, connectivity of patches. It does so by estimating the area within various distance bands away from meaningful edge, by seral stage, for the entire subwatershed. This method is in contrast to other indices of habitat fragmentation that typically rely on estimating perimeter length in relation to interior area for specific patches (Harris and Silva-Lopez 1992), or on more abstruse indices of fractal dimensions or distributions of patch size (O'Neill and others 1988) that can be hard to relate to actual species' responses. Using more complex indices of habitat patch patterns may be difficult in evaluating fragmentation effects for a variety of wildlife guilds across a myriad of patches that make up a subwatershed. Also, defining a habitat patch (from which perimeter and area measurements are obtained) is a tricky judgment. Finally, the distance-band tool has already been incorporated into software commonly used in National Forests of the Blue Mountains (Hitchcock and Ager 1992), although it remains to be empirically validated for species other than elk.

Evaluating watersheds—Once probability distributions of potential use are estimated for a cluster of subwatersheds, trends may become evident for the watershed as a whole. One might detect such trends by assessing the number or percentage of subwatersheds that favor elk, young forest, or old forest species within a watershed. Connectivity of habitat for unitive guilds might also be assessed by identifying subwatersheds that appear to be "weak links" (low use probabilities) relative to surrounding subwatersheds.

To illustrate, consider a hypothetical watershed comprised of 10 subwatersheds (fig. 4); 5 favor elk or multitype guilds, 3 favor unities associated with young forest, and 2 favor unities that use old forests.

Assessment of these spatial conditions might provide insight as to deficiencies and needs of particular guilds within a watershed. Such assessments would help managers identify opportunities for designing management goals to balance the needs for managing dissimilar species and guilds. This balancing could be done within and among subwatersheds and watersheds across an entire National Forest.

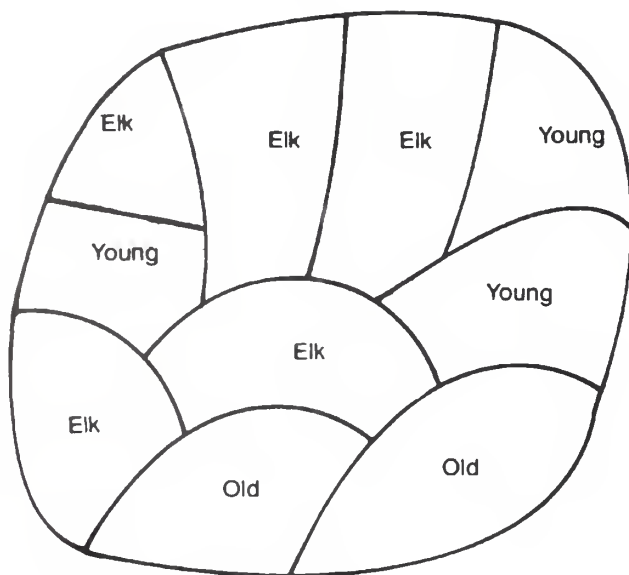


Figure 4. Hypothetical watershed composed of 10 subwatersheds: 5 favor elk or multitype species, three favor young forest species, and 2 favor old-forests species.

Habitat allocation for elk and untype species—Which of the three landscapes in figures 1, 2, and 3 is best for wildlife? The answer depends on one's objectives. Management that favors edge-associated species (fig. 3) does not provide optimal conditions for habitat-interior species that use large, unfragmented landscapes. Likewise, management solely aimed at minimizing fragmentation of old forests (fig. 2) does not provide optimal conditions for multitype species that use several vegetation seral stages and edges, or for untypes that occur in unfragmented, young forests.

How should dissimilar needs be accommodated within a single landscape? What specifically should be the desired future conditions in such landscapes? The short answer is that a balance must be struck among competing interests. Balance can be achieved at the subwatershed and watershed scales through manipulating patch sizes and arrangements. At different times, too, a given area can serve to provide unfragmented and fragmented conditions.

Conceptually, such manipulation requires the following steps:

- ☐ providing large, well-connected patches of old forests (fig 2);
- ☐ providing large, well-connected patches of young forests (fig. 1);
- ☐ compromising the size and connectivity of both old and young forests as a trade-off to sustain each over time (fig. 5); and
- ☐ providing some habitat interspersions among old and young forests as an outcome of the compromise (fig. 5).

This same process can then be repeated at the scale of the watershed, and again at the scale of a District or Forest. Of course, the practicality of any such optimal pattern must be fitted to the ground with consideration for roads, geologic hazards, other existing land allocations, and other factors.

Also, there are other management considerations for a featured species like elk that might be compatible with the requirements of untype species. For example, management to reduce elk vulnerability to harvest requires large, well-connected patches of mid-seral or old forests and low densities of roads (tables 1 and 2). Such a management strategy would favor old-forest species as well (table 2).

The outcome of a compromise strategy (fig. 5) meets less than the maximum possible habitat requisites of both multitype and untype guilds. Moreover, such a strategy may not meet the individual needs of sensitive, threatened, or endangered species. This possibility points to the obvious: explicit goals must be set at subwatershed and watershed scales, for both single species and dissimilar wildlife guilds, for trade-offs evaluated among each, and for designs implemented that likely favor one or more species or guilds over others. Only then can current conditions and effects of proposed actions be judged against desired objectives.

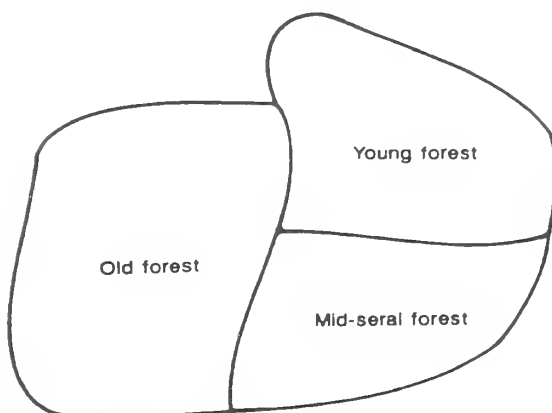


Figure 5. Hypothetical subwatershed of 1800 acres that would yield a probability distribution above 0.5 for old-forest species, and above 0.3 for both young-forest species and elk.

Objectives do not have to specify the layout design of habitats within a landscape; instead, they could describe a range of probabilities of potential use of the landscape. In this way, descriptions of desired future conditions would be flexible enough to allow for various on-the-ground solutions, with a variety of specific schedules of activities in space and time to meet the stated objectives.

Although such an approach might account for management needs of multiple species and guilds, the needs of sensitive, threatened, and endangered species must be addressed first. Single-species management cannot be abandoned for the sake of guild or multispecies management when the goal is to achieve a more holistic, ecosystem approach of landscape designs for wildlife. Ecosystem management is thus not a substitute for species management. Rather, it is additive and complementary.

Recommendations—Like most forest ecosystems of North America, past management in the Blue Mountains appears to have favored elk and other multitype species through increasing fragmentation of disjunct seral stages. Current National Forest Land and Resource Management Plans (“Forest Plans”) could stand to address the needs of unitype species in a holistic manner, especially those associated with old forests. The amount of undisturbed old forest remaining in the Blue Mountains is scant and fragmented, as is true with late-successional and old-growth forests in western Oregon and Washington (Johnson and others 1991).

This situation is exacerbated by the fact that landscapes of the Blue Mountains are naturally fragmented. Applying our method across multiple subwatersheds and watersheds of the Province would likely help identify conditions that favor multitype guilds over unitypes. We recommend that such an assessment be done to validate this premise. We also recommend that the validity of this method be tested through research. Both of these efforts in tandem would help provide new insights for managing wildlife from an ecosystem perspective.

Example 2: Managing for Sustainable Native Fish Faunas in Eastern Oregon and Washington

In this example, we explore conditions and methods for managing multiple species of native fish in eastern Oregon and Washington. The premise is that managers of eastside forests should manage for native coldwater stenotherms, that is, fishes with very narrow physiological tolerances and that require the highest quality water.

Coldwater stenotherms are declining on the eastside because of landscape problems resulting from abusive land-use practices. These species include the most prized sport fishes of North America and are of great commercial and cultural value. We argue that management for these featured, threatened, endangered, and sensitive species, and other species having moderate to high risk of extirpation, will lead to maximum species diversity of all fishes within the catchment basin. This approach is consistent with the principles of sustained-ecosystem management and a coarse-filtered approach. To understand why this is true, a brief synopsis of the ecology of fishes in streams is needed. The following section summarizes information on stream ecology as it applies to riverine fishes (Bayley and Li 1992).

Stream reaches and fish distributions: theory—In general, streams can be subdivided into two major subsystems connected by a transition zone, which can be either abrupt or gradual. The upper zone is shaded, small, steep, swift, rocky, highly oxygenated, and cold. The fishes that live in this zone, the rhithron, are coldwater stenotherms with high metabolic rates. They feed on aquatic insect drift and benthic invertebrates. Terrestrial drift is especially important because the riparian canopy reduces primary productivity and herbivorous insects are few. The lower zone, the potamon, is exposed to sunlight, large, of low gradient, sluggish, composed of smaller substrates, lower in dissolved oxygen, and warm. Fishes inhabiting this zone are warmwater fishes with low metabolic rates, tolerant of anoxic conditions, and ones that feed on a wider array of food. Piscivory, herbivory, and detritus feeding are more prominent trophic modes in the potamon community. The transition zone between the rhithron and potamon is composed of a mixture of these types of fish assemblages as well as coolwater, transitional forms.

The number of fish species is greater downstream than upstream. Different assemblage patterns (species combinations) occur depending on the degree to which shifts in physical gradients are abrupt (Rahel and Hubert 1991). If change is gradual, the number of species increases downstream in an additive manner because the transition zone is wide and the coldwater and warmwater faunas tend to overlap. If change is abrupt, patterns of zonation occur because the transition zone is narrow and the two types of faunas are more segregated. Patterns of distribution can shift up or downstream depending on the quality and quantity of water.

Stream reaches and fish distributions: management implications—Warmwater species are more abundant than coldwater species and the extent of warmwater reaches far exceeds those that are cold. Therefore, extending the coldwater zone further downstream increases species diversity of the catchment basin as a whole, as well as promoting the numbers of sensitive (coldwater) species. Species diversity is often indexed by combining species richness and equitability (relative abundance) of individuals among species. Ironically, managing for species diversity alone can reduce species richness in reaches of the upper basin because the more diverse species, the warmwater fishes, are pushed further downstream. The catchment basin is the most appropriate scale to conduct management; however, because it can include the entire fish fauna, it is an ecosystem on which boundaries can be placed for management and evaluation purposes (Frissell and others 1986).

Adaptation of stream fishes to disturbance—Evidence suggests that stream fishes have adapted to recurring patterns of disturbance over evolutionary time (Bayley and Li 1992, Meffe 1984, Resh and others 1988). The fish fauna of the Pacific Northwest has not adapted well to the radical modifications to the ecosystem caused by human activity (Li and others 1987, Reeves and Sedell 1992, Wissmar and others 1993).

Among the more serious threats are introductions of alien species. Alien species change the rules governing species assemblage structure and impose new rules on land managers. Native species that compete with or are preyed upon by alien species may become more sensitive to activities such as logging, which increases sedimentation and temperatures and results in the loss of coarse woody debris that creates and maintains pools and riffles. However, most of the documentation that alien species outcompete or directly exclude native fish species is correlative. Further direct autecological, experimental studies are needed to better determine the extent to which native species may have declined because of introduced species.

Alien species often predominate in systems that are badly disturbed by humans. Such effects described by Elton (1958) hold true for aquatic systems (Li and Moyle, in press; Moyle 1976). For instance, introduced smallmouth bass (*Micropterus dolomieu*) are now recognized to be major predators of native chinook salmon (*Oncorhynchus tshawytscha*) (T. Poe, pers. comm.; Tabor and others, in press). Once, smallmouth bass might have been excluded from chinook rearing areas by cold water, but elevated water temperatures caused by human activity now permit smallmouth bass to reside in chinook salmon rearing habitat in the John Day Basin where in 20 years they have expanded their range 640 miles upstream.

Types of disturbances—When large woody debris falls into streams, the riparian forest provides raw materials for habitat creation and habitat structure for fishes (Gregory and others 1991). This structure buffers large floods by providing refuges for fishes. When riparian vegetation and the flood plain remain intact, floods create new habitats and redistribute structural and organic materials within the aquatic ecosystem. Otherwise, floods are destructive (Junk and others 1989, Gregory and others 1991). For example, clearcut logging can cause catastrophic landslides (Lamberti and others 1991), decreased nutrient retention of the stream (Lamberti and others 1989), and resistance of the fish fauna to catastrophic floods (Fausch and Bramblett 1991, Pearsons and others 1992). Reduction of the flood plain and riparian forests alters the hydrograph, elevates stream temperatures, increases the silt burden, reduces habitat complexity and availability, and increases frequencies of flash flooding on eastside landscapes. Summer low flow conditions for coldwater fishes are more harsh because of water diversions and changes in runoff patterns. Silt from logging operations reduces spawning grounds (Platts and others 1989) by suffocating fish eggs

(Reiser and White 1988). Elevated water temperature from logging can increase summer temperatures, adversely change the forage base of fishes, and cause a decline of fish standing crops (Graynoth 1979). Reduction of the riparian canopy on eastside streams caused by livestock grazing causes similar problems. Elevated stream temperatures stress coldwater fishes while diminishing their prey base (Li and others, in press; Tait and others, in review). Destruction of riparian vegetation has reduced the capacity of eastside basins to buffer the fish fauna from flash floods (Pearsons and others 1992).

Theory of resilience of stream fishes to disturbances—Successional patterns of fish assemblages in streams are different from those of terrestrial organisms (Vannote and others 1980). Successional patterns in streams are spatial rather than temporal (Fisher 1983). Stream fishes, especially in the Pacific Northwest are specialized inhabitants of specific environments and are considered coldwater specialists, warmwater specialists, small stream forms, and big river forms (Bayley and Li 1992). Specialization for temporal stages of ecological succession are not observed (for example, pioneering species); instead, with changes in environmental conditions, the affected fauna relocates during recolonization and in response to periodic disturbances such as floods and droughts (Matthews 1986, Matthews and others 1988).

Fishes are exposed to profound changes in water quality and quantity over an annual cycle and exhibit strong patterns of seasonal movement (Junk and others 1989). Recurring disturbances act like a reset button on a computer. In streams providing refuges, habitats can be quickly recolonized and faunal elements restored in a matter of months (Freeman and others 1988, Matthews 1986, Matthews and others 1988). But flood plains and riparian forests must remain intact; otherwise, recolonization will take decades.

Management implications of disturbances—Because one does not have to manage for different successional stages, managing for biodiversity in lotic ecosystems is different than in terrestrial ecosystems. To maintain biodiversity, all faunal elements should be present within the basin. For this example, managing for the most sensitive species—the cold-water fishes—should benefit the fauna as a whole.

To transplant or introduce alien species to lotic ecosystems is undesirable because, once established, they are extremely difficult to remove. Problems they create will further constrain human activities because the native fauna is often more sensitive to human-caused or natural changes in the physical environment than is an established alien fauna. For example, the range of habitats occupied by the eastern brook trout is increasingly limited in its native waters because of displacement by introduced salmonids (Fausch and White 1981, 1986; Larson and Moore 1985). Alien salmonids dominate in areas where the habitat has been altered. To avoid this scenario in eastern Washington and Oregon, the most important factor is to preserve the functions of the riparian forests and the floodplain. Unnatural landscape disturbances must be minimized and human patterns of land use should mimic natural patterns of environmental variation whenever possible (Poff and Ward 1989, Resh and others 1988).

Sensitive fauna as indicators of forest health: background on river fishes of eastside forests—The species richness of fishes in a catchment basin reflects its zoogeographical history and the condition of its watershed (Bayley and Li 1992, Hocutt and Wiley 1986, Hynes 1975). Management can affect both factors. We can affect zoogeography by creating or eliminating barriers to dispersal and by introducing species. Watershed condition affects the composition of fishes from the available species pool because water flows downhill. Therefore, disturbances at the top of the watershed can affect the water quality and habitat availability in the catchment downstream.

Zoogeographical history reveals that fish taxa of the Pacific Northwest have been subjected to periodic, immense geological and climatic changes perhaps unparalleled in the rest of the continent (McPhail and Lindsey 1986, Minkley and others 1986). These changes include the massive and periodic Bretz floods in the Columbia Basin, tectonic uplift, glaciation, and volcanism. The fauna of the lower Columbia Basin reflects these major geologic upheavals, in that species located there are extremely well suited for dispersal and colonization over long distances (Li and others 1987). More than 50 percent of the fishes can disperse

through the sea (McPhail and Lindsey 1986). This capacity has been compromised now because few areas are sufficiently intact to generate needed dispersants to disturbed areas. The tributaries of the mid-Columbia are much harsher environments for salmonids than the lower basins (McPhail and Lindsey 1986, Mullen and others 1992); they are more subject to drought and high temperatures. The mean standing crops (2-3 g/m²) of the Methow, Entiat, and Wenatchee rivers are among the lowest recorded for the western United States. River-wide means have not been determined for the John Day River, but standing crops in selected sites range from 0 to 15 g/m² (Li and others, in press), and we suspect that most reaches are at the low end of the range. The margined sculpin (*Cottus marginatus*) is restricted to the cooler streams in the Blue Mountains of southeastern Washington and northeastern Oregon and might be endemic (McPhail and Lindsey 1986).

The northern third of the Columbia Basin was affected by glaciation, is mountainous, and is comprised of cold, high-gradient streams. The following fishes appear to be remnants of a preglacial, western, coldwater fauna: pygmy whitefish (*Prosopium coulteri*), lake chub (*Couesius plumbeus*), burbot (*Lota lota*), slimy sculpin (*Cottus cognatus*), and the bull trout (*Salvelinus confluentus*) (McPhail and Lindsey 1986). These fishes are scattered throughout the West in mountainous areas of relatively pristine conditions and appear to be confined to coldwater habitats.

Drainages of southeastern Oregon were subject to at least three major oscillating periods of desiccation and inundation during the late Miocene to the Pleistocene. The oscillations resulted in massive extinctions of lake-adapted forms and the relict distribution patterns of today. The surviving fauna of each dry period found refugia and "were poised to expand and recolonize areas during the next wet phase" (Minkley and others 1986). The problem is that the western fish fauna is on the verge of disappearing completely because of human activity (Minckley and others 1986, Minckley and Douglas 1991). Although small relict populations might be going extinct, the paleontological record certainly suggests that conservation meet biodiversity objectives.

Sensitive fauna as indicators of forest health: management implications—Eastside management should focus on the habitat requirements of coldwater native fishes, which will also benefit native warmwater fishes because water quality for the basin will improve. We hypothesize that the resiliency of a fish fauna to human disturbance of a catchment basin (for example, salvage logging, fire suppression, creation of logging roads and water diversions, grazing, and application of pesticides) is related inversely to the number of species:

- ☐ of threatened, endangered, and sensitive status;
- ☐ of special concern;
- ☐ with high or moderate risk of extirpation; and
- ☐ with localized distributions, represented in its fish communities.

This hypothesis is an extension of the Index of Biological Integrity proposed by Karr and others (1986). The distribution and abundance of coldwater fishes should be used as indicators of biological integrity for the drainage.

To assess the resiliency of fish faunas in catchment basins and the health of watersheds on various National Forests, we mapped the reported distributions of species found: east of the Pacific Crest Scenic Trail in National Forests in Oregon, Washington, or both states; and inside National Forests or up to 25 miles outside of National Forests (hereafter referred to as species associated with National Forests) (figs. 6 and 7, table 5). The reported distributions of fish associated with National Forests east of the Cascades Mountains were also shown beyond 25 miles of National Forests. Species included in the maps belong to at least one of the following categories (next page):

- ☐ threatened, endangered, or special concern species (Williams and others 1989);
- ☐ sensitive species of Oregon (threatened or endangered species, or species which might qualify for threatened or endangered status in the future; Marshall and others 1992);
- ☐ salmonids of high or moderate risk of extinction (Nehlsen and others 1991);
- ☐ fish of localized distribution (found within less than 8400 km² in a state) and associated with National Forests; and
- ☐ other fish associated with National Forests.

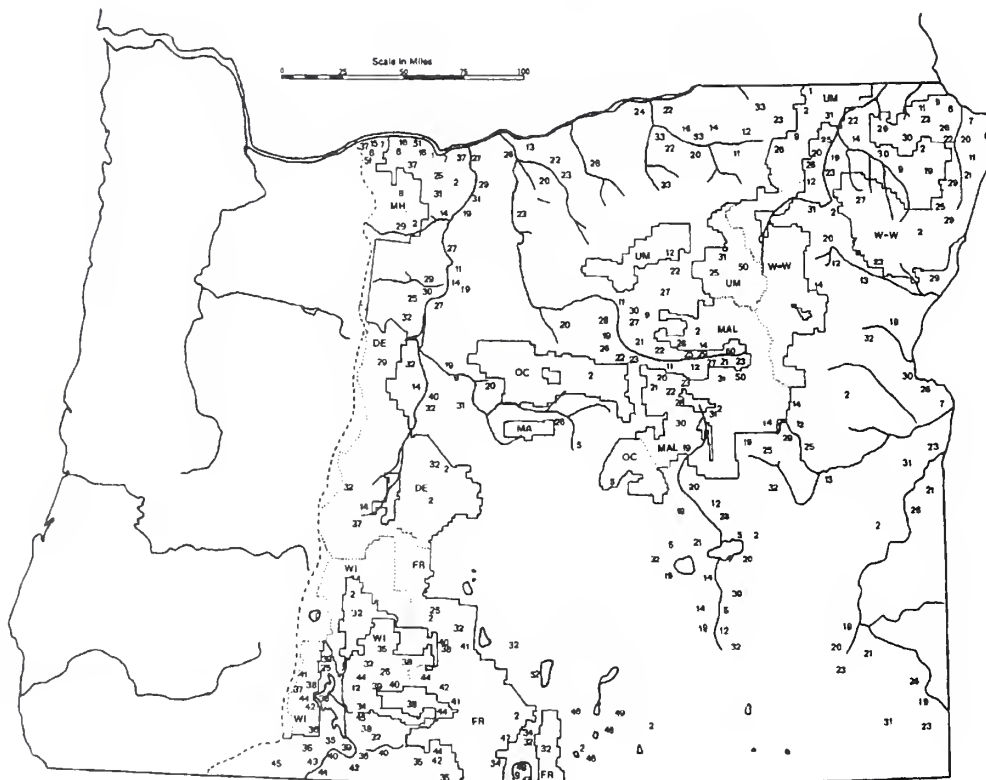


Figure 6. Distribution of fish associated with National Forests east of the Cascade Range in Oregon. (See table 5 for key to species names.) Codes for National Forests are: DE = Deschutes, FRE = Fremont, MAL = Malheur, MH = Mount Hood, OC = Ochoco (MA = Maury Ranger District), UM = Umatilla, WI = Winema, and WW = Wallowa-Whitman.

Some of the fishes in these designations are unique populations at the level of subspecies, races, or stocks. The data were obtained from faunal guides, publications, and lists of the status of native fishes (Behnke 1992, Currens and others 1990; Haas and McPhail 1991; Howell and Buchanan 1992; Knutson and others 1992; Lee and others 1980; Marshall and others 1992; McPhail and Lindsey 1986; Minckley and others 1986; Mullen and others 1986, 1992; Nelson 1968; Nehlsen and others 1991; Williams and others 1989; Wydowski and Whitney 1979).

Results show that threatened, endangered, or sensitive fish species occur on every National Forest in eastern Washington and Oregon. The total number of fish taxa that are threatened, endangered, species of special concern, species with localized distribution, or species with high or moderate risk of extirpation, is inversely proportional to the resilience of catchment basins in National Forests. The decreasing order in this resilience index of National Forests in eastern Oregon was: Malheur (3 fish taxa), Ochoco (3),

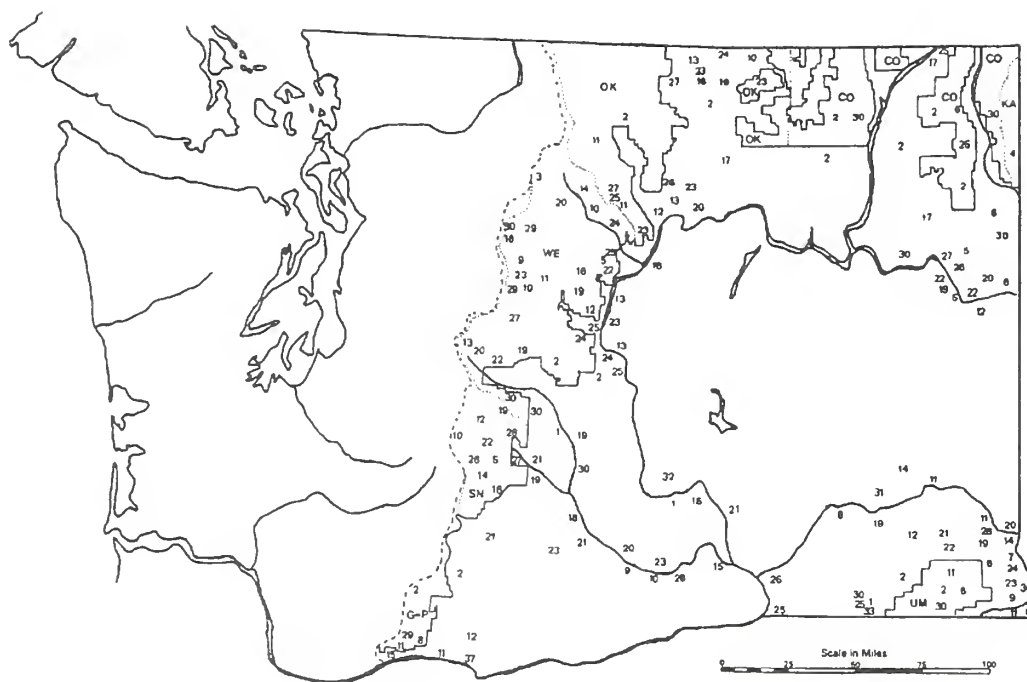


Figure 7. Distribution of fish associated with National Forests east of the Cascade Range in Washington. (See table 5 for key to species names.) Codes for National Forests are: CO = Colville (KA = Kaniksu Ranger District), GP = Gifford Pinchot, OK = Okanogan, SN = Mount Baker-Snoqualmie, UM = Umatilla, and WE = Wenatchee.

Deschutes (4), Mount Hood (4), Umatilla (4), Wallowa-Whitman (5), Winema (10), and Fremont (11). Hence, natural or human disturbances to fish communities seem to have been most adverse in Fremont and Winema National Forests. The decreasing order in the resilience index of National Forests in eastern Washington was: Mount Baker-Snoqualmie (2), Gifford Pinchot (3), Colville (4), Okanogan (4), Wenatchee (5), and Umatilla (6). These indices suggest an overall lower resilience for catchment basins in National Forests in Oregon than in Washington. When sensitive species listed by the State of Oregon were added to the resilience index, differences in relative order of resilience among catchment basins associated with National Forests in Oregon became more evident: Ochoco (4), Deschutes (5), Malheur (5), Mount Hood (6), Umatilla (7), Wallowa-Whitman (7), Winema (10), and Fremont (14). The State of Washington has not issued a list of sensitive species of fish.

Many species with localized distributions were exclusively associated with the Winema and Fremont National Forests. Some of these species were also classified as sensitive (figs. 6 and 7, table 5). The total number of species of fish, for all categories combined, associated with National Forests in eastern Oregon were: Wallowa-Whitman (23), Umatilla (20), Malheur (19), Fremont (18), Mount Hood (15), Winema (15), Ochoco (13), and Deschutes (11). In eastern Washington, these totals were: Wenatchee (21), Okanogan (18), Umatilla (16), Colville (12), Mount Baker-Snoqualmie (12), and Gifford Pinchot (11) (table 1).

Example 3: Management for Species Closely Associated with Old-Growth Forests of the Pacific Northwest

In this example, we summarize a recent evaluation of species viability conducted in the Pacific Northwest (Thomas and others 1993). Here, we discuss the methods used to conduct a viability risk analysis of species closely associated with late-successional and old-growth forests. This project was completed in response to a court order to evaluate potential effects on old-growth species of implementing a conservation strategy for the northern spotted owl on National Forests.

Table 5--Native species of fish in National Forests and Ranger Districts east of the Cascades Range in Oregon (OR), Washington (WA), or both; National Forests cited, parenthetically have fish within 25 miles.

Status of fishes: E = endangered, T = threatened, SE = sensitive, SC = special concern, dashed line = not reported
Species code corresponds to reported locations of fish in figures 6 and 7

National Forests and Ranger Districts by State			
Species code	Scientific name	Oregon	Washington
1	<i>Percopsis transmontana</i>	Umatilla (Mount Hood)	-- (Gifford Pinchot, Umatilla, Wenatchee)
2	<i>Oncorhynchus mykiss</i> ssp. SC-OR	All?	All?
3	<i>Cottus cognatus</i>	--	Wenatchee
4	<i>Catostomus catostomus</i>	--	Kaniksu
5	<i>Cottus bairdi</i> ssp. SE-OR SC-OR	Ochoco (Malheur, Maury, Umatilla)	Snoqualmie, Wenatchee (Colville, Okanogan)
6	<i>Oncorhynchus clarki</i> ssp. SC-OR	Wallowa-Whitman (Mount Hood)	Colville, Umatilla --
7	<i>Acipenser transmontanus</i>	Wallowa-Whitman, Mt. Hood	(Umatilla)
8	<i>Oncorhynchus kisutch</i> SE-OR	Mount Hood	Gifford Pinchot
9	<i>Lampetra tridentata</i> SE-OR SC-OR	Wallowa-Whitman, Umatilla (Deschutes, Malheur)	Wenatchee (Umatilla)
10	<i>Oncorhynchus nerka</i> SC-OR	Mount Hood? Deschutes? --	Gifford Pinchot, Wenatchee (Colville, Okanogan)
11	<i>Oncorhynchus tshawytscha</i> SE-OR	Wallowa-Whitman, (Malheur, Mount Hood, Ochoco, Umatilla)	Gifford Pinchot, Okanogan, Umatilla Wenatchee
12	<i>Richardsonius balteatus</i>	Umatilla, Winema (Malheur, Wallowa-Whitman)	Snoqualmie, Wenatchee (Gifford Pinchot, Okanogan)
13	<i>Rhinichthys falcatus</i>	(Wallowa-Whitman)	Wenatchee (Okanogan, Snoqualmie)
14	<i>Prosopium williamsoni</i>	Malheur, Deschutes (Mount Hood, Umatilla, Wallowa-Whitman)	Snoqualmie, Wenatchee (Gifford Pinchot, Okanogan)
15	<i>Lampraea ayresi</i>	--	(Gifford Pinchot)
16	<i>Cottus asper</i>	--	Snoqualmie, Wenatchee, (Okanogan)
17	<i>Prosopium coulteri</i>	--	(Colville Okanogan)
18	<i>Gasterosteus aculeatus</i>	--	(Okanogan, Wenatchee, Snoqualmie)
19	<i>Catostomus colombianus</i>	Malheur (Ochoco, Umatilla, Wallowa-Whitman)	Snoqualmie, Wenatchee (Colville, Okanogan, Umatilla)
20	<i>Catostomus macrocheilus</i>	Wallowa-Whitman, Malheur (Maury Ochoco Umatilla)	Wenatchee (Okanogan, Umatilla)
21	<i>Catostomus platyrhynchus</i>	Malheur (Ochoco, Wallowa-Whitman, Umatilla)	Gifford Pinchot, Snoqualmie, Umatilla)
22	<i>Rhynchichthys osculus</i>	Malheur, Wallowa-Whitman, Umatilla (Ochoco)	Snoqualmie, Wenatchee (Colville, Okanogan)
23	<i>Ptychocheilus</i>	Malheur, Wallowa-Whitman	Okanogan, Wenatchee
24	<i>Mylocheilus caurinus</i>	--	Wenatchee, (Okanogan, Umatilla)
25	<i>Salvelinus confluentus</i> SE-OR, SC-OR, SC-WA	Fremont, Umatilla, Wallowa-Whitman, Winema (Deschutes, Mount Hood, Malheur)	?

Table 5 (continued)--Native species of fish in National Forests and Ranger Districts east of the Cascades Range in Oregon (OR) or Washington (WA), or both; National Forests cited, parenthetically have fish within 25 miles. Status of fishes: E = endangered, T = threatened, SE = sensitive, SC = special concern. dashed line = not reported -- Species code corresponds to reported locations of fish in figures 6 and 7

Species code	Scientific name	National Forests and Ranger Districts by State	
		Oregon	Washington
26	<i>Acrocheilus alutaceus</i>	Malheur, Umatilla, Wallowa-Whitman (Ochoco, Maury)	Snoqualmie (Colville, Okanogan, Umatilla)
27	<i>Cottus rhotheus</i>	Wallowa-Whitman (Deschutes, Mount Hood, Malheur, Ochoco, Umatilla)	Okanogan, Wenatchee (Colville)
28	<i>Lampetra richardsoni</i>	Malheur (Ochoco)	Snoqualmie
29	<i>Cottus confusus</i>	Deschutes, Wallowa-Whitman (Malheur, Umatilla)	Gifford Pinchot, Wenatchee
30	<i>Rhinichthys cataractae</i> T-WA	Malheur, Wallowa-Whitman (Deschutes, Mount Hood, Ochoco, Umatilla)	Colville, Umatilla, Wenatchee (Kaniksu, Snoqualmie)
31	<i>Cottus beldingi</i>	Malheur, Umatilla (Maury, Mount Hood, Ochoco, Wallowa-Whitman)	(Umatilla)
32	<i>Gila bicolor</i> ssp. E-OR, T-OR, SC-OR	Deschutes, Winema, Fremont (Malheur, Wallowa-Whitman)	--
33	<i>Cottus marginatus</i> SE-OR	(Umatilla)	(Umatilla)
34	<i>Catostomus occidentalis</i> SE-OR, SC-OR	Fremont	--
35	<i>Catostomus luxatus</i>	Winema (Fremont)	--
36	<i>Lampetra similis</i>	Winema	--
37	<i>Cottus perplexus</i>	Deschutes, Mount Hood, Winema	Gifford Pinchot
38	<i>Cottus tenuis</i> SC-OR	Fremont, Winema	--
39	<i>Cottus princeps</i>	Winema	--
40	<i>Gila coerulea</i>	Fremont, Winema (Deschutes)	--
41	<i>Lampetra lethophaga</i>	Fremont, Winema	--
42	<i>Cottus klamathensis</i>	Fremont, Winema	--
43	<i>Catostomus rimitulus</i> SC-OR	(Winema)	--
44	<i>Catostomus snyderi</i>	Fremont, Winema	--
45	<i>Chasmistes brevirostris</i>	Winema (Fremont)	--
46	<i>Catostomus warnerensis</i> E-OR	(Fremont)	--
47	<i>Hesperoleucus</i> <i>symmetricus mitrulus</i> SE-OR	Fremont	--
48	<i>Cottus pitensis</i>	(Fremont)	--
49	<i>Gila bicolor eurysoma</i> SC-OR	(Fremont)	--
50	<i>Oncorhynchus clarki</i> <i>lewisi</i>	Malheur, Umatilla (Wallowa-Whitman)	--
51	<i>Oncorhynchus clarki</i> <i>clarki</i> SE-OR	Mount Hood	--
52	<i>Gila bicolor oregonensis</i> SC-OR	(Fremont)	--

The evaluation had three phases: identifying plant and animal species closely associated with old-growth forests and components of old-growth forests; evaluating potential effects on long-term viability of each species, under planning alternatives presented in a previous environmental impact statement; and identifying mitigations for habitat management to help ensure a high likelihood that all affected species would not be extirpated from the National Forests as a result of management actions. The process also addressed scientific uncertainty and lack of information that could influence the outcome of the evaluations of species viability. As per the court order, the evaluations were qualitative, based on the best available scientific information and professional judgment, but were not quantitative analyses of population and habitat dynamics.

This evaluation extended far beyond previous assessments of old-growth species (Johnson and others 1991, Lehmkuhl and others 1991, Ruggiero and others 1991) by including consideration for plant and animal taxa. This approach was inspired by the evaluations of how spotted owl planning will also provide for other species as conducted by Anthony and others (1992) for the Draft Spotted Owl Recovery Plan.

Identifying old-growth species—The following process was used to identify species associated with old-growth forests of the Pacific Northwest. First, a long list was constructed of species that find optimal habitat conditions in mature or old-growth forests for one or more life needs. The long list drew from existing literature and included more than 1200 species.

From this long list, a short list of species closely associated with old-growth forests or components (large snags, live trees, and down wood) was constructed based on a compilation of data on distribution, ecological attributes, and habitat studies of each species. A set of repeatable rules were developed by which each species was assessed for membership on the short list (Thomas and others 1993). Next, all species on the short list were evaluated for effects on viability resulting from each of the spotted owl planning alternatives, and mitigation options were identified for those species that ranked less than medium high in viability under the selected alternative. Five panels of species experts were convened to refine the short list and to assess viability and mitigations for plants and terrestrial vertebrates. Invertebrates were assessed through contracts with regional experts, and fish were evaluated with aid from a concurrent panel's (PacFish) analysis of anadromous salmonids (USDA 1992). The short list eventually included 667 species evaluated in all or in portions of their range, or fish stocks (hereafter, "species or ranges"): 190 fungi, lichen, and nonvascular plants; 122 vascular plants; 149 invertebrates associated with old-growth and riparian habitats; 112 anadromous salmonid fish stocks; 21 amphibians (no species of reptiles was identified as closely associated with old-growth forests); 38 birds; and 35 mammals.

Evaluation of potential viability effects—The expert panels evaluated the potential effects on 50-year viability of each species. They did so by ranking each combination of species and planning alternatives according to a five-class rank order scale depicting degree of protection (table 6). The 50-year time frame chosen for the evaluation models a harvest period for most old-growth forest on lands suitable for timber production in National Forests. From the viability rankings, each species was assigned to one of four categories of extirpation risk: high (viability rankings of medium low or low), medium (viability rankings of medium), low (viability rankings of high or medium high), and unknown (not enough scientific information available by which to judge potential effects on viability).

In combination with existing Forest Plan standards and guidelines, each species was rated for potential effects on viability under each spotted owl planning alternative. Results indicated that existing Forest Plans, in combination with the strategy selected in the previous environmental impact statement for conservation of spotted owl habitat, would protect some 280 species or ranges, or about one third of all species closely associated with old-growth forests. This strategy still leaves some 387 species or ranges at risk of extirpation on one or more National Forests.

Identification of mitigations—For these 387 species or ranges, additional mitigations for habitat management were developed to help ensure they would not become extirpated over a 50-year period.

Table 6--Five-class ranking scale used to assess viability of populations of species closely associated with old-growth forests in the Pacific Northwest under various planning alternatives (Source: Thomas and others 1993:264)

HIGH - There is a high likelihood that the population(s) of the species would stabilize in National Forests within the range of the northern spotted owl. This provides broad latitude for natural catastrophes and uncertainties in knowledge. The likelihood of widespread or complete extirpation is low.

MEDIUM HIGH - There is a moderately high likelihood, somewhat better than 50/50, that the population(s) of the species would stabilize in National Forests within the range of the northern spotted owl. This provides limited latitude for natural catastrophes and uncertainties in knowledge. There is less than a 50/50 likelihood of widespread or complete extirpation.

MEDIUM - There is roughly a 50/50 likelihood that the population would stabilize, and a similar likelihood of widespread or complete extirpation in National Forests within the range of the northern spotted owl. This provides extremely limited latitude for natural catastrophes and uncertainties in knowledge.

MEDIUM LOW - There is less than a 50/50 likelihood that the population would stabilize, and greater than 50/50 likelihood of widespread or complete extirpation in National Forests within the range of the northern spotted owl. This provides no latitude for natural catastrophes and uncertainties in knowledge.

LOW - It is highly unlikely that the species' population would stabilize, and there is high likelihood of widespread or complete extirpation in National Forests within the range of the northern spotted owl. There is no latitude for natural catastrophes and uncertainties in knowledge.

Cumulatively, these mitigations included recommended standards and guidelines, developed first for those species or species groups with the broadest distributions—in this case, for species of riparian habitats (with a focus on the 112 stocks of at-risk anadromous salmonid fish) and for marbled murrelet (*Brachyramphus marmoratus*), a Federally listed threatened species. Mitigations for riparian habitat and for marbled murrelet habitat would also provide for an additional 42 species or ranges. Then, other mitigations were developed and added for the remaining species still at risk: rare and locally endemic species (17 species or ranges) and other upland forest matrix species (7 species or ranges). With the accumulation of all mitigation steps, habitat for some 459 species or ranges would be provided so as to avoid extirpation.

Species with no information—Scant or no scientific information is available for judging the viability effects on the residual 208 species. Of this total, 23 species would likely be afforded some (unknown) degree of protection based on their ecological similarity to other species that occupy habitats and ranges already provided in the mitigation steps above. The remaining 185 species were truly unknown, and protection for them could not be judged. They included 19 fungi (mushrooms), lichens, and nonvascular plants; 8 vascular plants; all 149 invertebrate species, which as a group are poorly known; and 9 mammals, all of which were species of bats. For these unknown species, and for some others only potentially protected, further inventories and scientific studies were strongly recommended.

Conclusions—This example demonstrates the feasibility of evaluating vast numbers of plant and animal species, and the need to consider the full array of species in a habitat planning program. Assessing all species avoids the problems related to using ecological indicator species, indicator guilds, or featured species in management planning. The investment in time, money, and personnel for this scale of venture, however, precludes its use in everyday management. Thus, information and databases, developed for this project, on ecological requirements of each species are being prepared for publication and general use (Thomas and others 1993), to avoid “set-up” costs associated with gathering such basic data for future assessments.

This example demonstrates the potential of multiple-species evaluations and planning. However, Thomas and others (1993) emphasized the need to treat these viability evaluations and proposed mitigations as preliminary management hypotheses needing further quantification, refinement, and testing. Still, this multiple species approach, even within these limits, is a big step toward ecosystem management.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Continued total reliance on a species-by-species approach to preserve biodiversity likely will fail because of inefficiency and economics, and the associated direct and opportunity costs (Thomas and others 1993:8).

The three examples chosen for this chapter highlight the vast differences in approaches possible for multiple-species and ecosystem management. Each case presents unique solutions to different management needs. For species groups requiring conflicting habitat and landscape attributes—interior environments of habitat patches and species edges or several types of habitat patches—the elk habitat management example illustrated one approach to combining management direction. The fish habitat management example emphasized how to consider zoogeography, site history, geology, and habitat ecology of aquatic systems in developing optimal management regimes for cold-water fishes. Consideration of ecosystem processes will become a greater focus in species management over time. The old-growth species management example demonstrated that requirements of all species of a biotic community can indeed be considered; that effects on potential viability can be qualitatively judged to help identify species requiring additional management consideration; that new standards and guidelines for helping ensure long-term viability can be crafted to meet the needs of an entire biotic community; and that scientific uncertainty and unknowns can be directly factored into viability evaluations and management recommendations.

What is the need to evaluate species and habitats in such detail? If species extinctions and speciations (evolution of new species) occur naturally, do we need to concern ourselves with such in-depth analyses? Records indicate that natural extinctions occur typically over a much longer time (2 to 4 orders of magnitude longer) than the life of National Forest management plans. Local extinctions have occurred not at constant rates over recent geologic history, but rather in sporadic episodes, such as the local extinctions of many forest dwelling plant and animal species from the Mount St. Helens 1980 eruption and from the prehistoric floods of the Columbia River (McPhail and Lindsey 1986). Speciation occurs over even longer periods than the recent human induced global “extinction spasm,” about 3 to 5 orders of magnitude longer than the life of management plans.

Historical local and global extinctions of species are not a reasonable justification for accepting local extirpation of species resulting from management activities as natural events. Lynch (1989) investigated several modes of speciation. His results suggest that 71 percent of species extinctions through geologic time were due to one species evolving into several new forms and not due to irreparable loss to the lineage. Therefore, extinction is also the result of creative, generative processes in addition to degenerative, destructive ones. Extinction as an evolutionary process is often misperceived by laypersons as the end of a lineage. The accelerated loss of species resulting from recent human activities is clearly a separate and distinct phenomenon in geologic history.

The regulations implementing NFMA call for insuring viability of all native and desired nonnative species within each planning area (National Forest, 36 CFR 219.19). Given the present state-of-the-art, even predictions of effects, during 100 years—that result from implementing a relatively short-term, 10-year forest management plan—cannot begin to balance long-term speciation with short-term extirpation and local extinctions. But to rationalize local, management-caused extirpations by citing natural speciation is to submit to the tyranny of short-term decisions and to ignore the creative aspects of long-term evolution of new life forms. One of the three tenets of ecosystem management—conserving or restoring natural biodiversity—would be violated.

For many species, the question becomes: At what finest scales of space and time is it acceptable to allow local extirpations yet still maintain the population and species throughout the planning area, physiographic province, and region? The answer must vary according to several factors: degree of rarity of the

species and its selected habitat(s), or of a unique habitat; mandates of policy and dint of an accepted recovery plan for threatened or endangered species; and ecological attributes of the species, such as its metapopulation dynamics, degree of vagility, dynamics of immigration and emigration, and degree of habitat and resource specificity. For example, clearcutting an old-growth stand eliminates habitat for brown creepers (*Certhia americana*) on that site, yet the local population may continue to survive throughout the subwatershed if other old-growth forest stands persist. On the other hand, the same clearcut stand might have been the only location of colonies of red tree voles (*Arborimus longicaudus*) in the subwatershed. We must also consider that, for featured species such as ungulate game species, disturbance is necessary for producing substrates, cover, or resources for some life needs, such as forage.

Another example is instructive for threatened species management: the recent controversy over protection of a small bird—the California gnatcatcher (*Poliophtila californica californica*)—and protection of the highly fragmented coastal sage scrub of southern California. In this case, developers, conservationists, and government agencies are seeking a common solution to conserve the bird's remaining ecosystem, only 10 percent of which remains, rather than seek litigation focused on protecting the species per se under the Endangered Species Act. One proposal has as its compromise the destruction of parts of the bird's habitat under agreement by developers if adequate amounts of critical habitat are set aside elsewhere to sustain the bird and its ecosystem. In a coarse-filter approach, this plan would also provide for at least some of the habitat's other associated species, avoiding future legal battles over other threatened or endangered species associated with the coastal sage scrub habitat. The concept of protecting habitat of multiple species is fast becoming the favored approach to avoid conflicts over single-species management (Reinhold 1993).

This approach fits well with one of the primary stated purposes of the Endangered Species Act: "...to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved..." (Endangered Species Act, Sec. 2(b)). The outcome of the case with the California gnatcatcher might determine how future maintenance and recovery planning for threatened and endangered species are handled on both private and public lands. Likewise, the Forest Service must decide how to interpret its legal mandates, such as the Endangered Species Act and the National Forest Management Act.

Another consideration in managing for featured species in an ecosystem context is meeting the needs of Native Americans. Management programs are culturally biased for species of high commodity and social value to Euro-Americans to the exclusion of those favored by Native Americans (Hunn 1990). For instance, suckers, mountain whitefish, lamprey, and redbreast shiners are commonly considered "trash" fish by Euro-American sportsfishers. These same species are considered food fishes by the Sahaptin peoples (Native Americans of the mid-Columbia Plateau) and are held in high regard. Sculpins and crayfish are considered sacred icons and are not to be harmed. Black tree lichen (*Bryoria fremonti*), pine nuts, acorns, huckleberry, camas roots, and other plants are prized food items. Historically, many armed conflicts arose because of the insensitivity of Euro-Americans to adverse land use impacts on camas. This can cause conflicts in management policy because Native Americans retain rights to resources on lands ceded to the Federal Government. These rights have the same legal standing as treaties between sovereign nations. In keeping with Forest Service policy, it is incumbent to manage Forest Service lands to ensure substantial and sustainable yields of resources deemed important to native peoples.

In the end, successful integration of species and ecosystem management lies in clearly defining specific objectives at several scales of time and space and in proactively integrating all objectives. Successful integration of objectives can only be achieved by following the three basic principles of ecosystem management: to maintain or restore biodiversity, to maintain long-term site productivity, and to maintain sustainability of natural resource production. All activities, plans, and projects should be weighed at local, provincial, and regional scales against these three principles.

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Eastside Forest Management Practices: Historical Overview, Extent of their Application, and their Effects on Sustainability of Ecosystems

by

Chadwick D. Oliver, Larry L. Irwin, and Walter H. Knapp

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ABSTRACT

Forest management of eastern Oregon and Washington began in the late 1800s as extensive utilization of forests for grazing, timber, and irrigation water. With time, protection of these values developed into active management for these and other values such as recreation. Silvicultural and administrative practices, developed to solve problems at a particular time have lingered and created confusion and consternation when knowledge, values, and vegetation conditions have changed. The present condition of most eastern Oregon and Washington forests is the result of disturbance and regrowth processes coupled with historical management practices. Most areas contain high levels of insects, diseases, and fuels. Without many, diverse, creative, and active solutions, large fires and insect outbreaks will occur—with local loss of ecosystem and human values.

INTRODUCTION

This paper describes the history of forest management in eastern Oregon and eastern Washington. To do this, the area is divided into seven geographic subunits (fig. 1; table 1). The ecological patterns and land-use history are roughly similar in each subunit. Division into subunits allowed combining data based on National Forest areas and county areas. Sources of information are described in appendix A.

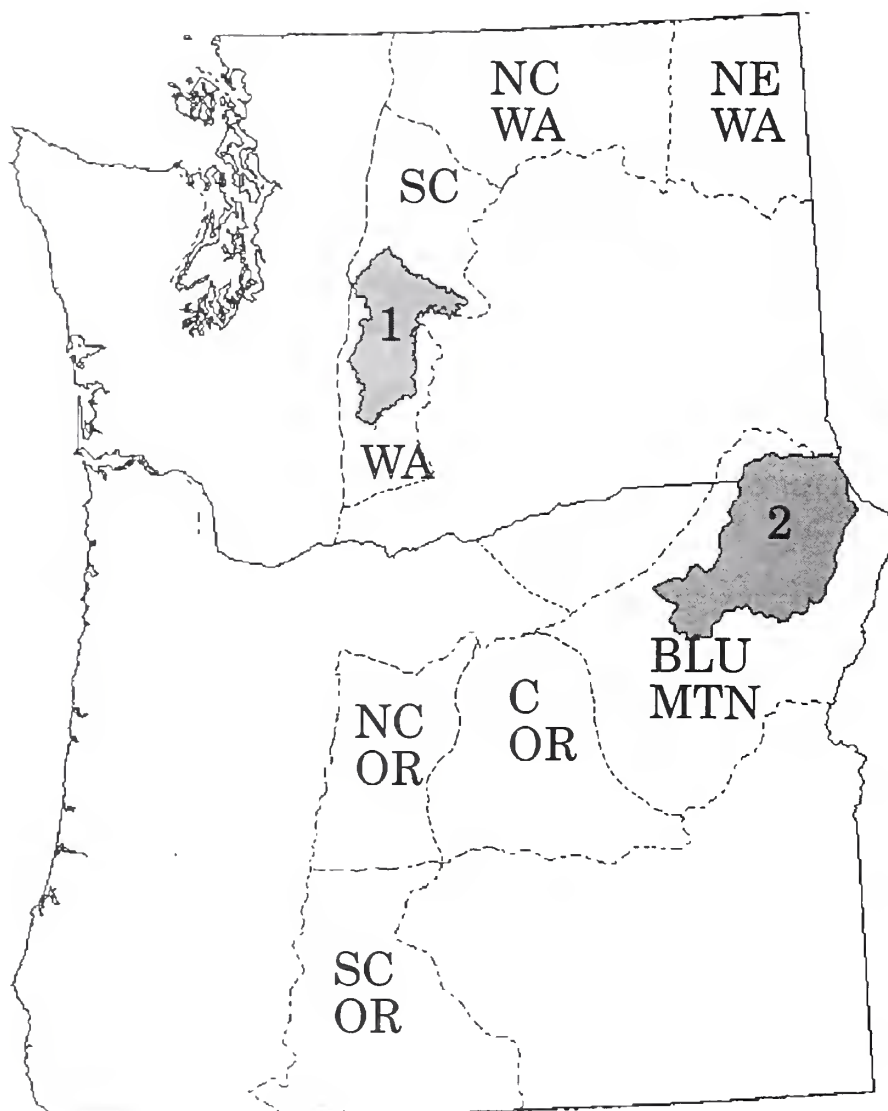


Figure 1. Subareas and subsampled river basins of eastern Washington and Oregon referred to in this report. Subareas, indicated by letters, correspond to table 1. Subsampled basins shown in dotted boxes. (1 = Yakima basin; 2 = Grande Ronde basin).

Table 1. Subareas of eastern Oregon and Washington (Figure 1), showing National Forests and counties associated with each area.

NORTHEAST WASHINGTON

Counties

Ferry County
Pend Oreille County
Stevens County

National Forests

Colville National Forest

CENTRAL OREGON

Counties

Grant County
Harney County
Crook County
Wheeler County

National Forests

Malheur National Forest
Ochoco National Forest

NORTH CENTRAL WASHINGTON

Counties

Okanogan County

National Forests

Okanogan National Forest

BLUE MOUNTAINS

Counties

Baker County (Oregon)
Grant County (Oregon)
Morrow County (Oregon)
Umatilla County (Oregon)
Union County (Oregon)
Wallowa County (Oregon)
Asotin County (Washington)
Columbia County (Washington)
Garfield County (Washington)

National Forests

Umatilla National Forest
Wallowa-Whitman National Forest

SOUTH CENTRAL WASHINGTON

Counties

Chelan County
Kittitas County
Yakima County

National Forests

Wenatchee National Forest

NORTH CENTRAL OREGON

Counties

Deschutes County
Jefferson County
Klamath County
Lake County

National Forests

Deschutes National Forest

SOUTH CENTRAL OREGON

Counties

Klamath County
Lake County

National Forests

Fremont National Forest
Winema National Forest

The Area

Eastern Washington and Oregon consist of about 25,230,000 acres of forest. Forests with sufficient tree densities and growth to produce more than 20 cubic feet per acre per year are considered commercial forest lands and comprise 80 percent of the total (table 2, USDA Forest Service 1982). Most of the forest in eastern Oregon and about 46 percent in eastern Washington (fig. 2) is in National Forests. Because a large amount of land is in National Forests, Forest Service management policies and practices exert a strong influence on forestry activities, and trends reported on National Forests generally reflect management practices on other lands as well.

Table 2. Characteristics of eastern Oregon and Washington lands. (USDA Forest Service 1982, 1991).

	EASTERN OREGON	EASTERN WASHINGTON
AREA (acres)		
Total	42,391,000	26,762,000
Range Area	20,313,700	7,236,200
Forest Area		
Total	14,656,000	10,574,000
Nonproductive ¹	3,508,000	1,552,000
Productive	11,148,000	9,022,000
U.S. Forest Service	9,838,391	3,627,489
National Wilderness	1,040,330	1,276,034
National Wild & Scenic River	12,000	0
National Recreation	400,569	0

¹ Land not capable of producing 20 cubic feet/acre/year in natural stands.

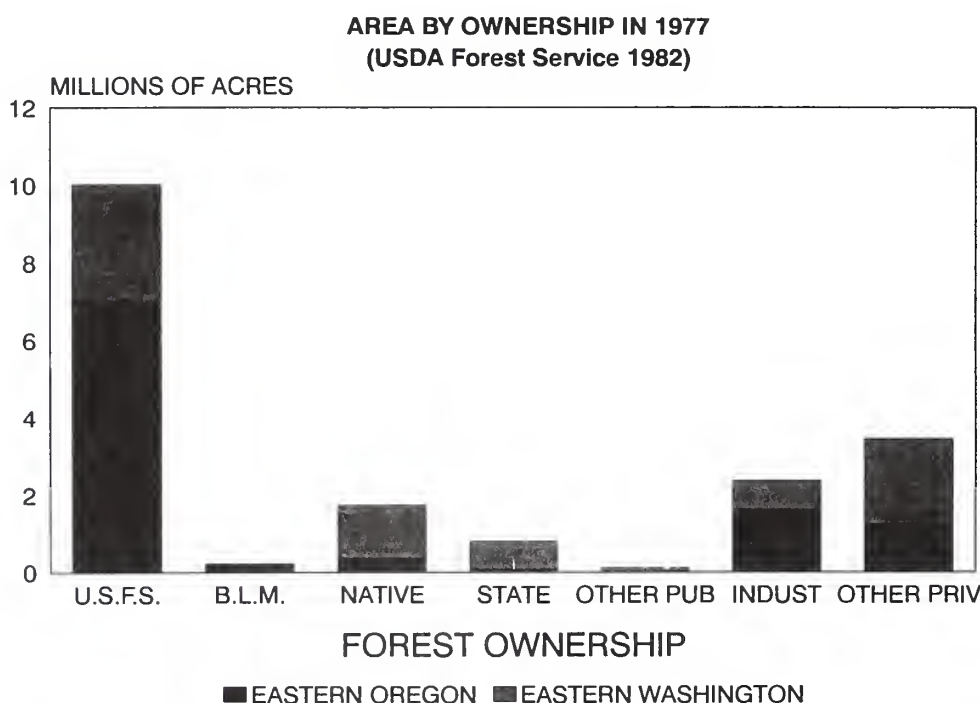


Figure 2. Most of eastern Oregon's productive forests are National Forest, as are about 35 percent of eastern Washington's productive forests. ("Productive" forest refers to land capable of growing more than 20 cubic feet per acre per year.) (USDA Forest Service 1982).

Forests contain a variety of species in both pure and mixed stands (fig. 3). Tree growth is poorest on forest lands at the low elevations where soil moisture is limiting, and at upper elevations, where the cold climate is limiting. In the middle elevations, where soil moisture is more favorable, tree growth is moderate or better. In addition, dry conditions and frequent droughts predispose trees to insects and diseases, especially if the stands become overcrowded. The stands can also become susceptible to fires if dead material accumulates. Historically, large and small disturbances—both stand-replacing and partially stand-replacing—affected forest stands, creating stand structures suitable for a variety of wildlife and plant species (fig. 4; Oliver and Larson 1990).

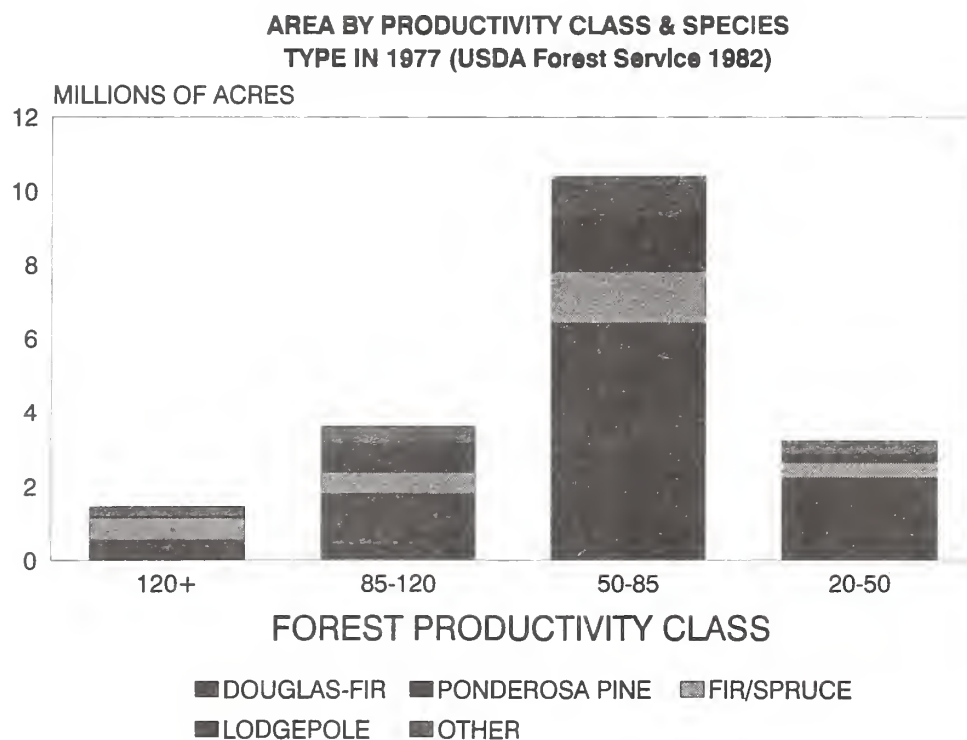


Figure 3. Most eastern Oregon and Washington forests are of relatively low productivity, but contain a variety of species (USDA Forest Service 1982).

Organization of This Report

This report is organized by management practices. Presentation of the history of each management practice will be subdivided into three periods: pre-1930, 1930 to 1960, and 1960 to the present. For each period, an overview of the forest condition and associated rural land-use practices will put management in context. Specific management activities will then be addressed according to their historical application and policy environment, the extent of application of the practice (as it is known or can be estimated), and the known and estimated effects of the management. Management activities listed below are those identified as most influential on current conditions by an interdisciplinary panel of scientists convened early in the project.

- ☐ **Fire management**—Fire management primarily consisted of fire suppression, but controlled burning is presented as well.
- ☐ **Grazing**—Horse, sheep, cattle, and elk grazing practices are presented as are associated range management practices.

- ❑ Mining—Methods of mining for minerals and precious metals and for gravel are presented.
- ❑ Timber harvest—Three aspects of timber harvesting are discussed: amount and type of harvest systems; equipment used in harvesting; and postharvest fuel treatment. For a description of timber harvest practices, see appendix B.
- ❑ Rading and access management—Road, railroad, and bridge construction and maintenance were done with varying degrees of quality control. Access allowed fire protection, insect and disease protection, timber harvest, and recreational opportunities.
- ❑ Pest management—Outbreaks of defoliators, bark beetles, and pathogens have been suppressed by various means. Outbreak and suppression histories are discussed.
- ❑ Riparian management—Three aspects of riparian management are discussed: flood control, irrigation, and riparian zone management.
- ❑ Wildlife management—Activities presented include the killing of livestock predators, protecting and enhancing populations of game animals for hunting, protecting and enhancing populations of rare or endangered species, and enhancing habitats (such as by creating snags).
- ❑ Wilderness management—Aside from sheep grazing and some other special uses, wilderness areas were left alone, although fires were suppressed.
- ❑ Silvicultural operations—Silvicultural operations include those management activities that change stand structure and composition. Recently, silviculture has also been applied to managing landscape patterns. Silvicultural operations discussed include planting, release (weed control), regeneration, thinning, pruning, fertilizing, tree improvement, controlled burning, and other activities.

HISTORY

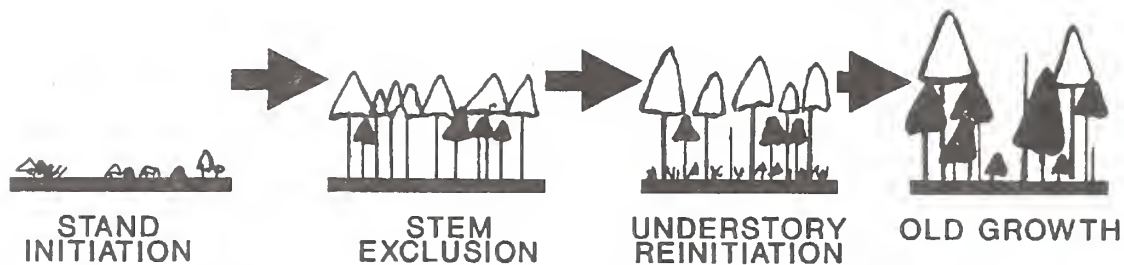
Pre-1930

Forests in eastern Oregon and Washington in the late 19th and early 20th centuries commonly contained open, parklike structures at low elevations. Frequent ground fires (Hall 1977, Volland and Dell 1981) maintained openness by burning most regeneration. The large trees were primarily fire-resistant ponderosa pine at the lower elevations, Douglas-fir and western larch at middle, and true firs at the higher elevations (LeBarron 1948). On cooler sites and at higher elevations, fires were less frequent; however, where they burned, all or nearly all of the trees were destroyed. Fires that burned hundreds of thousands of acres were common in the late 1800s (Walcott 1900, Gannett 1903) and occurred in northeast Washington as late as the 1920s. Where a hot fire did not destroy all overstory trees and ground fires did not quickly follow, stands of several cohorts (age classes) formed layered canopies with one or several species that resembled mixed-species stands that develop after a single, hot fire (fig. 4, Johnson and others 1993). Shade-tolerant true firs grew into stands and formed a dense understory where fire did not prevent them from doing so.

Forests in 1900 were a mosaic of many structures (fig. 4); open, recently burned areas and areas with dense stands in various conditions of regrowth after the hot fires. Pure or mixed species stands grew after the fires, creating a variety of layered or single-canopy forests. At various times, refugia of old stands were left in burned areas (Hessburg and others 1993) and refugia of open areas within regrown stands (Johnson and others 1993).

Settlements of Eastern Oregon began in 1843 as pioneers followed the Oregon Trail through the Blue Mountains (Skovlin 1991). Settlement of eastern Washington came later and settlement of northeastern Washington by cattlemen, farmers, and sheepherders came later still. Most rural residents lived on small farms, which increased in number until about 1920 to 1940 (U.S. Bureau of the Census). Farming and grazing were the main activities, and logging was limited to relatively accessible areas.

A. DEVELOPMENT AFTER STAND-REPLACING DISTURBANCE



B. DEVELOPMENT AFTER PARTIAL DISTURBANCE

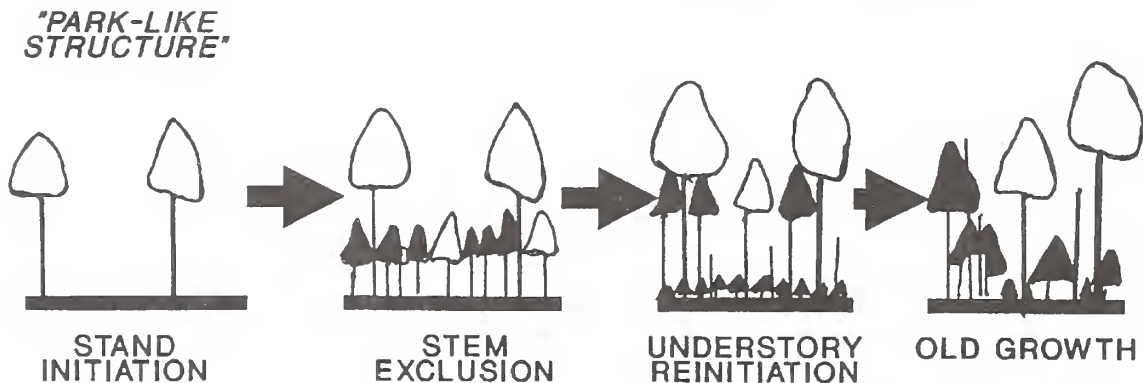


Figure 4. Historically, eastern Oregon and Washington forests developed after both stand-replacing and partial disturbances—usually fires. These disturbances and subsequent forest regrowth produced a variety of structures that were used by different animal and plant species (after Johnson and others 1993).

1930 to 1960

During this time, eastern Oregon and Washington underwent a great transition. Forests had begun to change with regrowth after earlier fires, and management became more intensive and effective on National Forests. Additionally, more and more people moved off the land and into the cities. They also began to view the forest as a source of beauty and thus became more interested in the activities that went on there.

In many places, the forests were similar to those of the earlier decades because harvesting had not been extensive. Some high-graded stands were becoming dense with many layers, and shade-tolerant true fir and other species were becoming more abundant in stand understories. Grazing was extensive in most areas (tables 3A, 3B; figs. 5, 6). Some large areas that had been previously burned were grazed, and others were developing as dense stands (Cobb 1988).

Improved mechanization, access, transportation, and communication meant foresters were able to inspect larger areas. Farm mechanization caused the number of farms and farm laborers to decline dramatically (U.S. Bureau of the Census), although farm size increased.

Rural land use and population changed dramatically. Some activities declined and others increased. Sheep grazing, for example, reached a peak, then declined (fig. 6), while cattle grazing and irrigation continued to increase. Trucks and automobiles continued to replace horses, and hydroelectric plants generated electricity. (Wissmar and others 1993).

1960 to the Present

Several decades of successful fire prevention have allowed a younger class of shade-tolerant tree species to grow beneath seral overstories, creating dense, closed stands. These stands, along with previously high graded stands, contain multiple cohorts and canopy layers, making them increasingly susceptible to diseases and insects. Stands growing after the fires during the late 1800s and early 1900s are overcrowded, as are the stands planted and thinned to close spacings in the 1950s and 1960s. Only small areas remain in meadow and grassy understories and open parklike stands in the forest are rare (fig. 7).

Land use has changed dramatically. The area of National Forests in either wilderness or spotted owl reserves (tables 3A, 3B, fig. 5) is much greater than the area grazed or harvested in the two subsample basins.

Table 3A. Extent of management activity per million acres for sampled area in Yakima Drainage Basin.
(Data available for subsample of about 350000 acres or less depending on activity.)

ACTIVITY	Pre-1900	1900-1920	1921-1945	1946-1966	1967-1992
FIRE SUPPRESSION					
fire starts	20	2,529	1,337	811	1,828
# suppressed	NA	1,581	26,011	811	1,828
lightning fires	NA	92	520	305	644
human fires	NA	1,469	1,044	506	1,184
av. wildfire ac.	NA	248	135	31	40
tot. ac. burned	NA	95,383	2,075	4,833	18,790
TIMBER HARVEST					
ac. clearcut	NA	NA	1,976	11,588	16,375
ac. shwd/shdtr	NA	NA	3,161	1,877	40,975
ac. thinned	NA	NA	1,976	118	10,591
ac. sel. harv.	NA	NA	208,475	11,427	19,040
ac. tractor yd.	NA	NA	164,646	10,666	28,762
ac. cable yd.	NA	NA	0	7,566	22,306
tot. MBF	NA	NA	265,640	461,616	931,171
major spp. harv.	NA	NA	NA	PP DF	DF WL
GRAZING					
Sheep					
# sheep	NA	55,403	56,409	30,433	8,231
ac. grazed	NA	288,998	338,525	306,339	240,592
AUMs allotted	NA	16,927	21,685	10,680	6,626
Cattle					
# cattle	NA	3,964	4,220	1,877	3,519
ac. grazed	NA	212,235	178,312	195,130	199,902
AUMs allotted	NA	11,096	15,343	5,485	6,049
Elk					
# elk	NA	NA	NA	NA	NA
ac. grazed	NA	NA	NA	NA	NA
AUMs allotted	NA	NA	NA	NA	NA
ROADING					
mi. railroads	26	53	53	53	0
mi. roads	99	176	290	672	2,251
RESERVE AREAS					
ac. wilderness	NA	NA	NA	65,303	318,525
ac. other	NA	NA	66,323	192,644	181,193
ac. WL/plant habitat	NA	306	NA	153	227,474
MINING					
# active claims	NA	NA	20	112	1,105
# prodt. claims	NA	NA	NA	NA	NA
ac. of claims	461	5,381	4,505	2,012	19,489
ac. by streams	NA	2,305	NA	NA	NA
FLOOD/IRRIGATION					
dams installed	NA	13	NA	NA	NA
mi. dikes installed	NA	NA	NA	NA	NA

1 Values vary because of differences in areas of available information.

Table 3B. Extent of management activity per million acres for sampled area in Grande Ronde Drainage Basin. (Data available for subsample of about 350000 acres or less depending on activity.)

ACTIVITY	PRE-1900	1900-1920	1921-1945	1946-1966	1967-1992
FIRE SUPPRESSION					
fire starts	46	75	203	651	1,382
fires suppressed	46	781	203	651	1,382
lightning fires	521	46	110	496	1,034
human fires	7	33	92	145	348
av.wildfire acres	282	192	2	1,039	1,050
tot. acres burned	1,971	7,826	4,385	17,368	45,383
TIMBER HARVEST					
acres clearcut	0	0	0	6,909	3,213
acres shwd/shdtr	0	0	0	11,604	37,216
acres thinned	0	0	0	5,992	22,651
acres sel.hvst.	0	0	32,435	17,963	27,031
acres tractor yd.	0	0	0	35,025	61,020
acres cable yd.	0	0	0	668	14,010
total M bd.ft.	0	0	729,782	53,973	717,532
major sp.hvstd.	NA	NA	PP	PP	PPDFWLGF
GRAZING					
Sheep					
# sheep	NA	301,153	420,253	510,535	327,062
acres grazed	NA	258,360	67,452	171,684	190,726
AUM's allotted	NA	107,484	93,273	470,518	1,653,176
Cattle					
# cattle	NA	190	59,363	66,139	368,429
acres grazed	NA	948	76,184	232,139	452,784
AUM's allotted	NA	1,137	444,277	414,294	1,536,512
Elk					
# elk	NA	0	0	352,543	1,891,434
acres grazed	NA	0	0	711,831	711,831
AUM's allotted	NA	0	0	2,115,258	11,348,605
ROADING					
miles rail'd	45	72	167	84	84
miles road	139	287	722	1,363	2,964
RESERVE AREAS					
acres wildern's	0	0	5,459	151,802	249,746
acres other	0	519,883	201,933	557	557
acres WL/pl hab.	0	0	0	0	5,489
MINING					
# active claims	123	357	168	0	8
# produc'g cl'ms	0	0	0	0	0
acres of claims	1,949	3,790	3,358	0	56
acres near stream	0	0	0	0	0
FLOOD/IRRIGATION					
# dams installed	0	0	3	0	0
miles dikes inst'd	0	0	0	0	0
1 Values vary because of differences in areas of available information.					

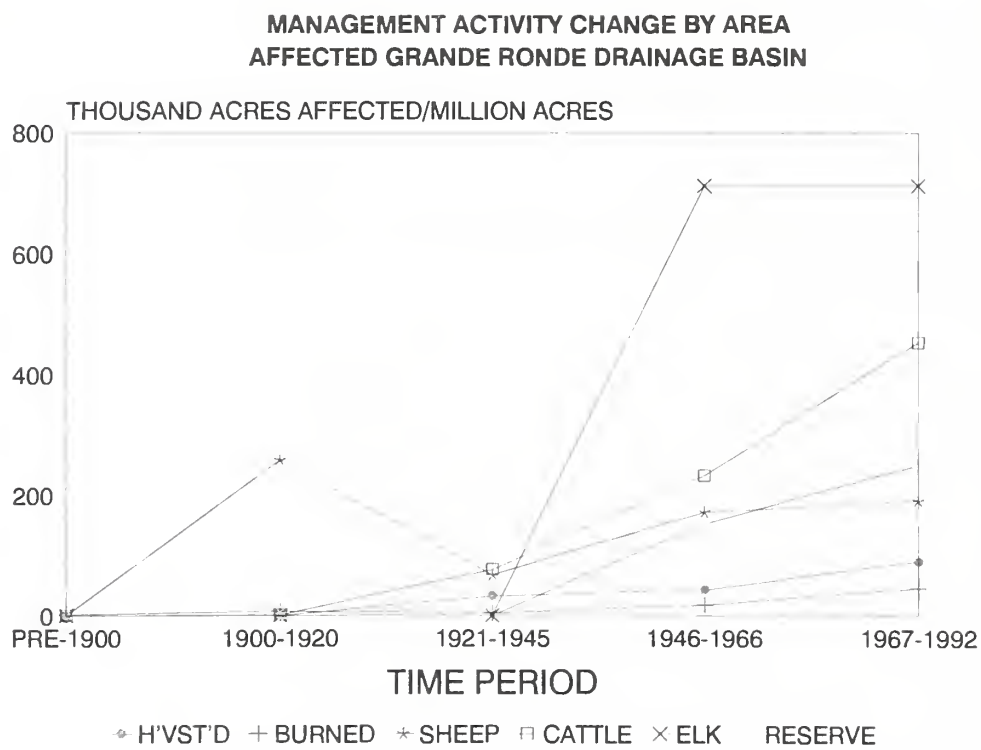
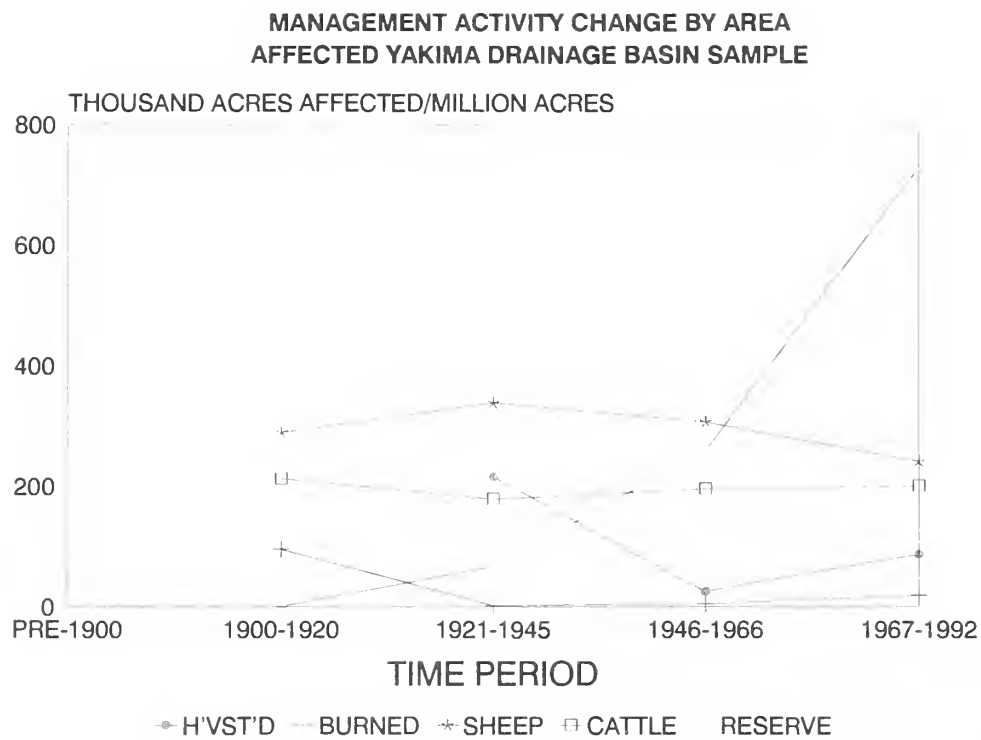


Figure 5. Change in acres affected by management activities in subsampled Yakima (5A) and Grande Ronde (5B) basins. (See fig. 1; tables 3A, 3B.)

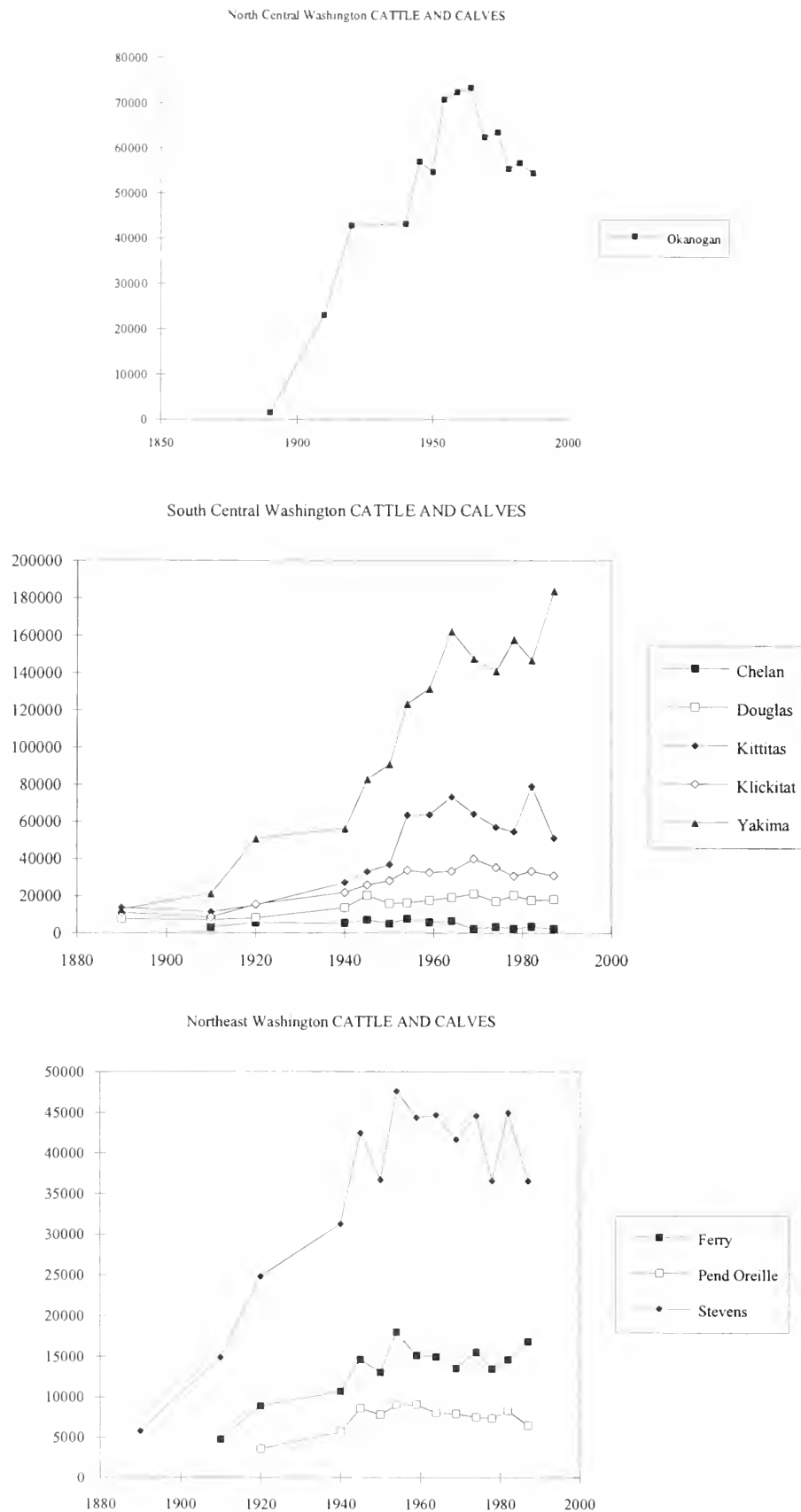
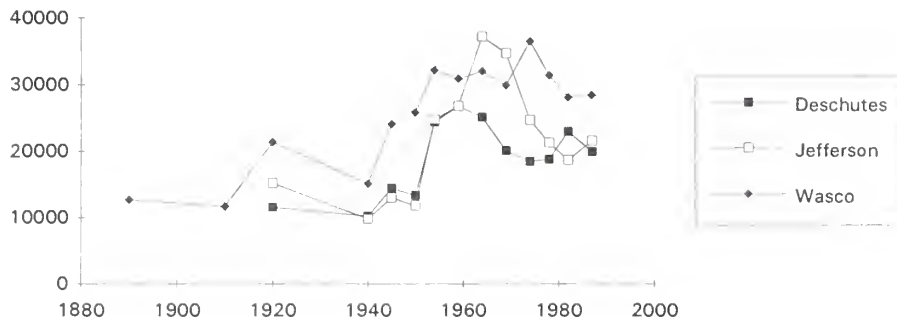
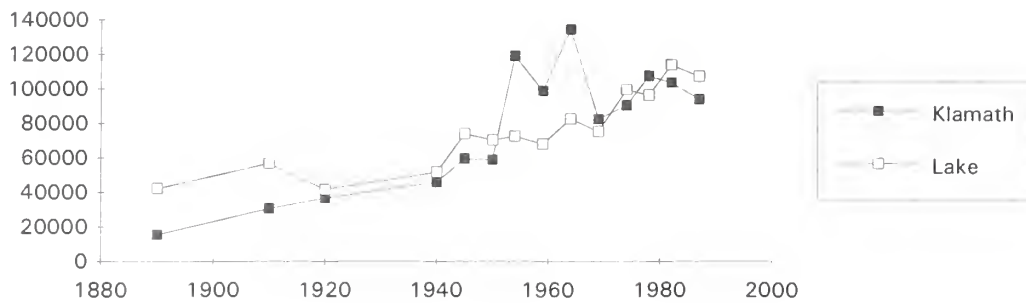


Figure 6A. Changes in cattle in eastern Washington during the past Century (U.S.Bureau of the Census). Not all animals were grazed in forests; however, the trend shows changing pressure on use of forests for grazing. Number of cattle and calves has generally increased in eastern Washington.

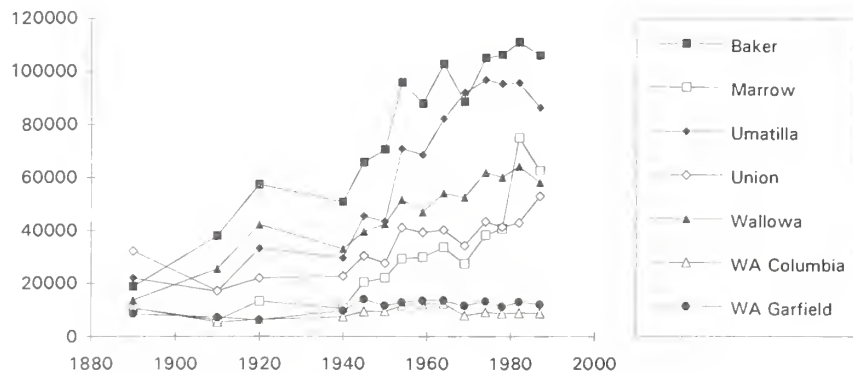
North Central Oregon CATTLE AND CALVES



South Central Oregon CATTLE AND CALVES



Blue Mountains CATTLE AND CALVES



Central Oregon CATTLE AND CALVES

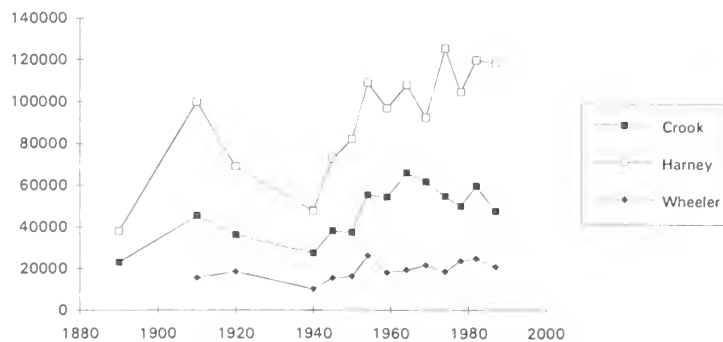
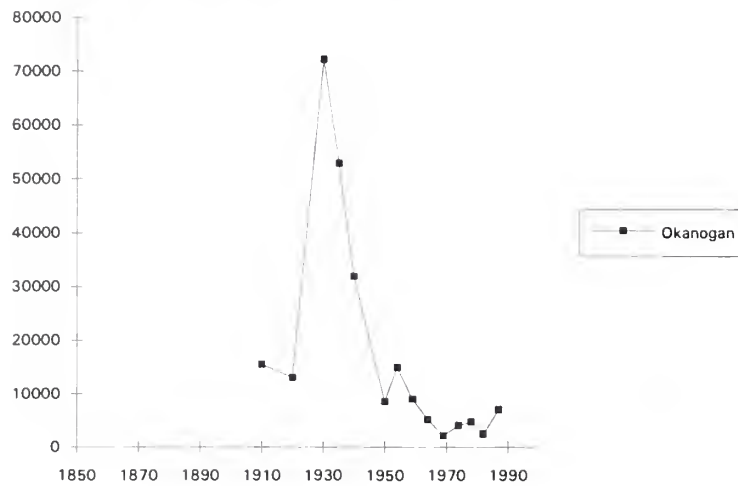
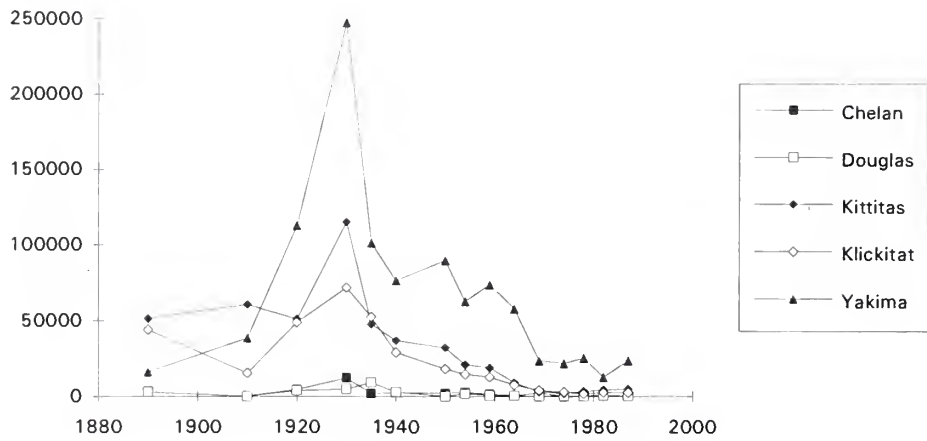


Figure 6B. Changes in cattle in eastern Oregon during the past Century (U.S.Bureau of the Census). Not all animals were grazed in forests; however, the trend shows changing pressure on use of forests for grazing. Number of cattle and calves has generally increased in Oregon in the past century.

North Central Washington SHEEP AND LAMBS



South Central Washington SHEEP AND LAMBS



Northeast Washington SHEEP AND LAMBS

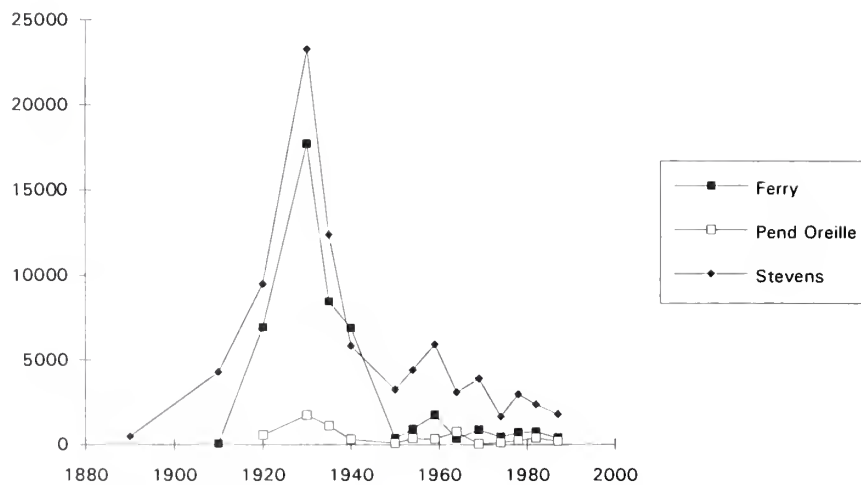


Figure 6C. Changes in sheep in eastern Washington during the past Century (U.S.Bureau of the Census). Not all animals were grazed in forests; however, the trend shows changing pressure on use of forests for grazing. Number of sheep and lambs increased until about 1935, then decreased dramatically.

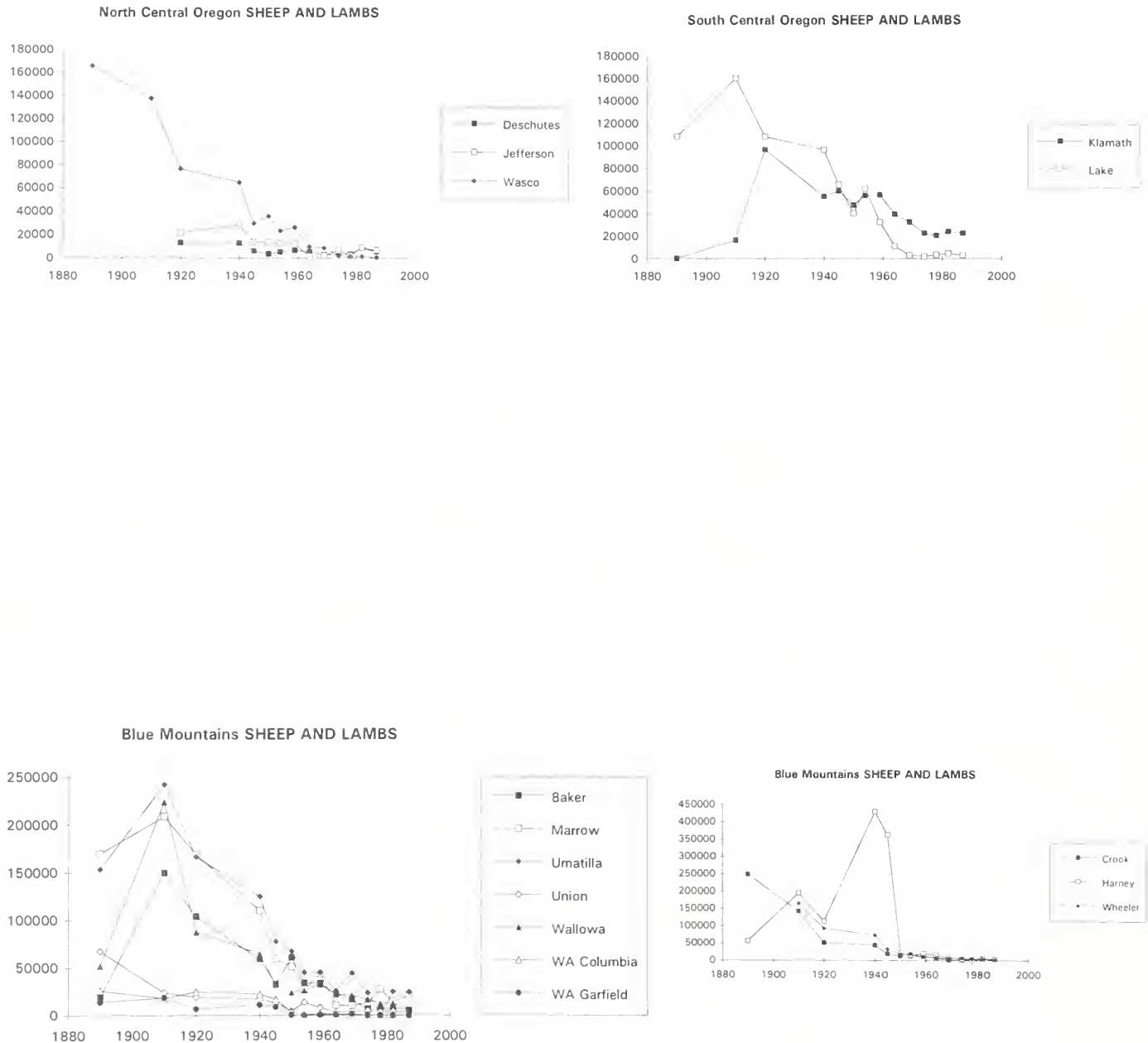
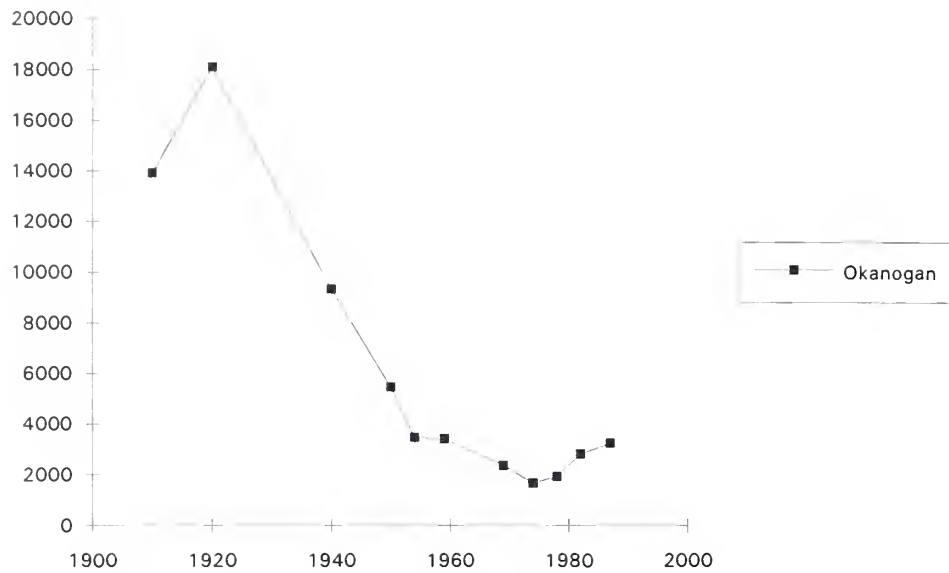
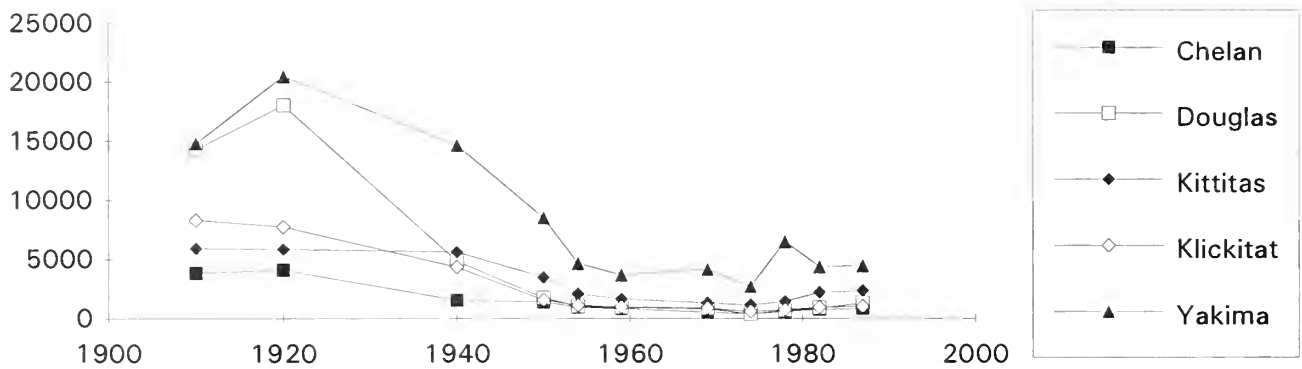


Figure 6D. Changes in sheep in eastern Oregon during the past Century (U.S.Bureau of the Census). Not all animals were grazed in forests; however, the trend shows changing pressure on use of forests for grazing. Number of sheep and lambs increased until about 1935, then decreased dramatically.

North Central Washington HORSES AND PONIES



South Central Washington HORSES AND PONIES



Northeast Washington HORSES AND PONIES

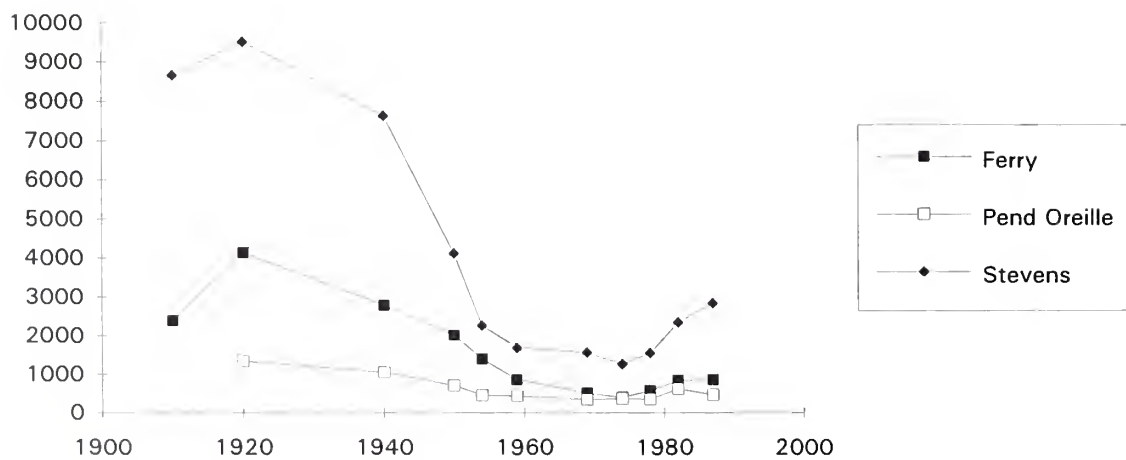
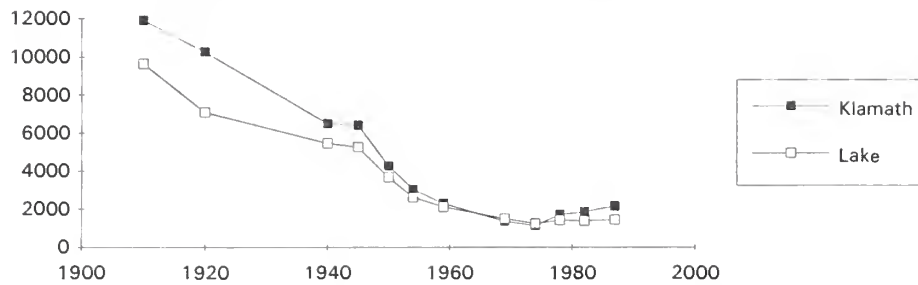
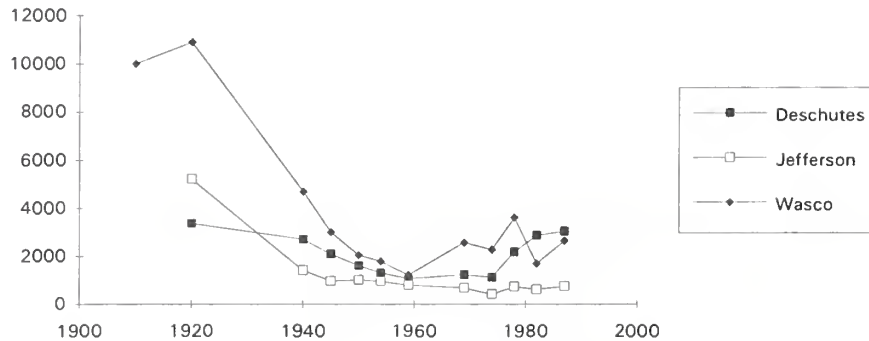


Figure 6E. Changes in horses in eastern Washington during the past Century (U.S.Bureau of the Census). Not all animals were grazed in forests; however, the trend shows changing pressure on use of forests for grazing. Number of horses and ponies has decreased dramatically during the past century.

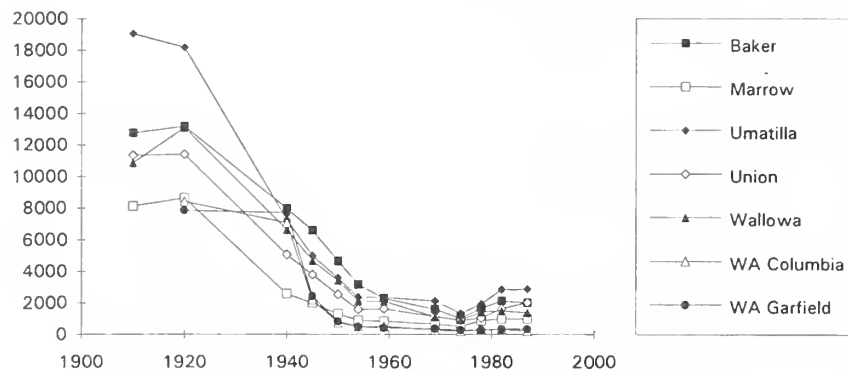
South Central Oregon HORSES AND PONIES



South Central Oregon HORSES AND PONIES



South Central Oregon HORSES AND PONIES



South Central Oregon HORSES AND PONIES

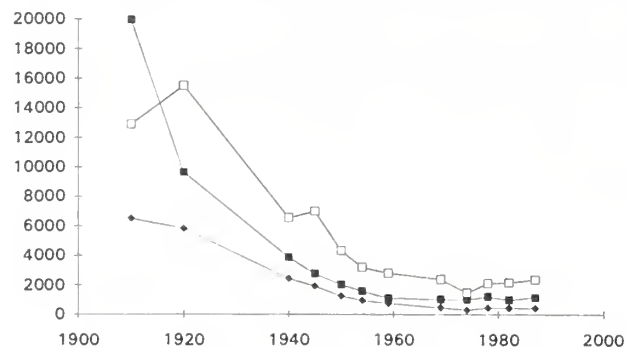


Figure 6F. Changes in horses in eastern Oregon during the past Century (U.S.Bureau of the Census). Not all animals were grazed in forests; however, the trend shows changing pressure on use of forests for grazing. Number of horses and ponies has decreased dramatically during the past century.

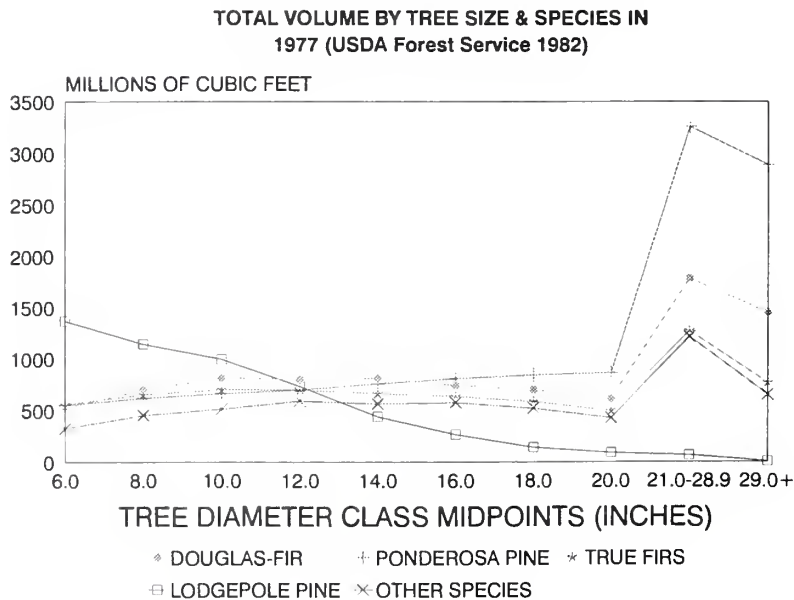
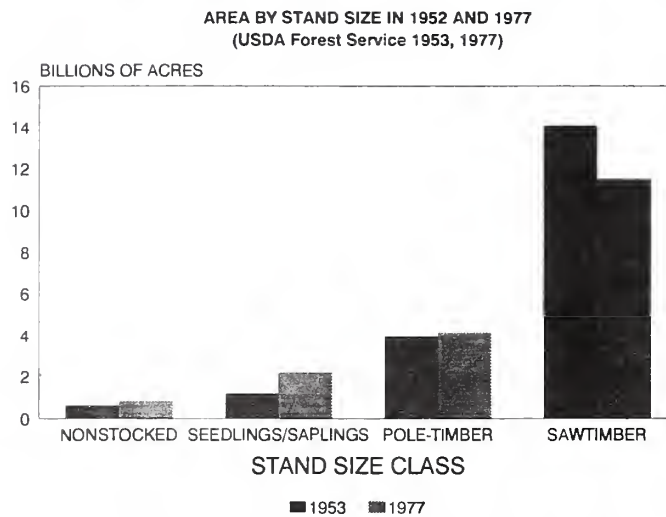
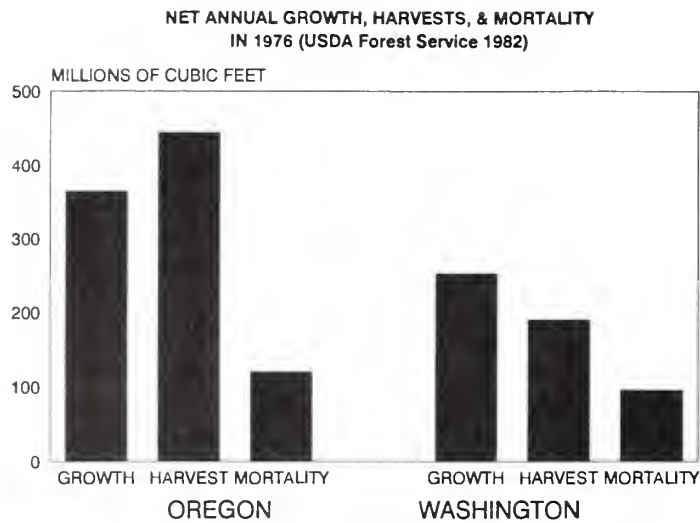


Figure 7. Effects of more intensive harvesting since the 1950s. (USDA Forest Service 1982). 7A: Mortality is still occurring—probably through suppression, insects and diseases, and fires. 7B: More area contains stands of small, crowded trees in the stem-exclusion stage (fig. 2). 7C: Trees of large diameters are still living in many places.

HISTORY OF MANAGEMENT PRACTICES

Fire

Pre-1930—People living in eastern and western Washington and Oregon in the late 19th century and early 20th century may have been responsible for large fires that swept through the forest at that time. Studies of regional fire patterns, however, suggest that fires also occurred naturally and in cycles (Agee 1993).

Ground fires that maintained parklike stands burned frequently at lower elevations. They were supplemented with settlement fires, early logging fires, and fires set by sheep and cattle herders when they left in the autumn to “green up” higher elevations for the next year (Plummer 1902). Early settlers complained about the smoke caused by these fires, and conservationists were concerned about loss of timber.

Forest Reserves—forerunners to National Forests—were created in 1891. A forestry commission was organized in 1896 to study the condition of the Forest Reserves and to suggest how they might be protected from fire (Steen 1976). Actual provision for management of the Reserves was made in the Organic Act of 1897; the precise meaning of “protection” and “management” evolved through time.

Fire suppression primarily protected resources and private property. Fire protection was recognized as necessary for investment in forest regeneration. Fires in western Washington in 1902 prompted the appointment of a State Fire Warden in 1903, and a State board of forest commissioners, formed two years later, was responsible for eastern and western Washington forests. Private groups contributed too, culminating in the Western Forestry and Conservation Association. The Federal government assisted States in forest protection through the Weeks Law of 1911 (Steen 1976). The Clarke-McNary Act of 1924 expanded on the Weeks Law and allowed further cooperation and funding among States and private landowners for fire protection.

One major obstacle to fighting fires was the enormous cash outlay needed to fight them. A single large fire had the potential to bankrupt a national forest. To prevent this, Congress passed an Act in 1908 that permitted the Forest Service to “deficit spend” in the event of forest fire emergencies (Agriculture Handbook 453 rev. 1983). The large fires of 1910 tested the Act, and the resulting deficit expenditures were approved by Secretary of Agriculture James Wilson. As a consequence, a system of double accounting was created: one set of economic criteria was applied to normal fire seasons, another to those seasons with major fires.

Another obstacle to fighting fires effectively was the lack of an organization and infrastructure. Forest Service permittees at the turn of the century were obligated to fight fire without compensation whenever their permit area was threatened. National parks could rely on U.S. Army troops to aid in fire suppression, but forest reserves had no ready pool of fire fighters (Pyne 1982). Fire guards were often called for small fires, and paid only for those days when they were working in the field.

The debate between those advocating strict control of all fires and those favoring “light burning” or prescribed fire began as early as the late 1800s when, for example, proponents of light burning in California spoke out in print (Pyne 1982), and they developed a following in areas with large expanses of pines, including eastern Oregon. The concept was favored by timber owners and others who saw light, periodic underburning as a method to reduce fuels, and therefore future conflagrations. Opponents saw the practice as nothing less than forest destruction because even “light” fires reduced humus and burned up reproduction.

Light burning was viewed by many in the Forest Service largely as a folk practice and not of any use to professional foresters. Systematic fire protection was called for by many of the agency's top officials. Coert duBois, an early Regional Forester, published *Systematic Fire Protection in the California Forests* in 1914, considered at the time to be the book on fire protection (Pyne 1982). His work helped give conceptual design to a Division of Fire Control created in 1915. Stuart Bevier Shaw and E.I. Kotok provided an almost constant flow of studies supporting the view that all fires damaged forests and should be suppressed while they were still small (Pyne 1982).

Lack of roads, mechanization, and an infrastructure of professionals and laborers limited early success with controlling fires. Tables 3A and 3B and figure 5 show that fires burned in some areas during this time. Fires covering hundreds of thousands of acres occurred in north-central Washington about 1900 and in northeastern Washington in the 1920s. Major fire complexes in 1902 and 1910 were particularly influential. The 1910 fires, in fact, so traumatized the Forest Service that they helped shape the Agency fire policy for over 30 years.

Early attempts at fire suppression successfully stopped many small ground fires near settled areas, and prevention efforts reduced the number of human-caused fires through a public relations program. Stands regrowing after burns of the late 19th and early 20th centuries did not have frequent ground fires to space trees; consequently, these stands are now overcrowded and susceptible to insects, diseases, and fires.

1930 to 1960—Fire prevention efforts became more intensive and effective with an expanded and improved road system. In 1933 the Civilian Conservation Corps (CCC) was created, which provided fire-fighting crews and presuppression programs, including roads. Chief Forester Silcox wrote in the 1936 annual report, "Perhaps the largest and most important contribution the Civilian Conservation Corps has made during the three years of its existence, has been in protecting the forests from fire" (Pyne 1982). Other specialty crews later supplemented and then replaced the CCC. The most important were smokejumpers, a corps especially adept at initial attack and the 40-man crew (later reduced to 20 firefighters and hotshots), a rapid deployment force for campaign fires. At about the same time, the Office of Civilian Defense organized the Forest Fire Fighters Service (FFFS). In 1961, after some experimentation with smoke jumpers, the Interregional Hotshot or IR crew program developed. It was composed of 20-man units that could be sent anywhere in the country to fight a fire. Cooperation among State and Federal agencies in fire fighting was enhanced through the Cooperative Forest Fire Prevention program (CFFP) begun in 1942. At the same time State and private industry created the "Keep America Green" program, which was initiated in the Northwest.

In 1935, flushed with CCC manpower and the Conservation programs of the New Deal, Chief Forester Silcox promulgated the so-called 10 a.m. policy, "an experiment on a continental scale" to break wildland fires in one massive effort. This policy stipulated that all fires must be controlled by 10 a.m. the next day. Efforts to promote prescribed burning continued to be dismissed. Not until 1943, did the Forest Service officially sanction even limited burning.

The fire-prevention activities have generally been described as successful. Nearly all fires that were started were suppressed and many traditional forms of burning were eliminated, but the total number of acres burned fluctuated greatly (tables 3A, 3B; figs. 5, 8), as did the total numbers of fires. Fires were small and frequent in eastern Oregon, and large and infrequent in eastern Washington (fig. 8). The proportion of the total forest area burned between 1946 and 1986 (table 4) is much less than the usual fire return interval (Agee 1993), indicating the period had relatively few fires. How much of the reduced fire frequency can be directly attributed to fire fighting efforts, and how much is the result of previous decades of large fires and grazing reductions to fuels is difficult to determine.

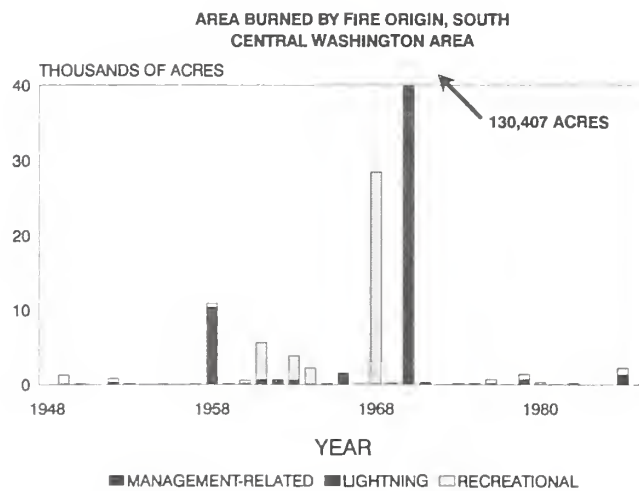
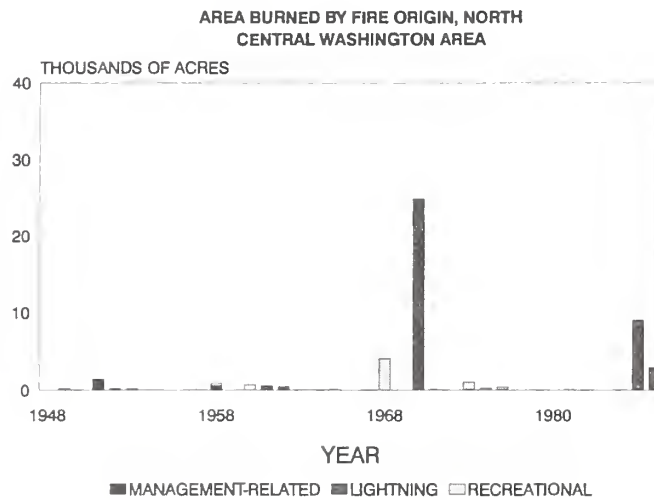
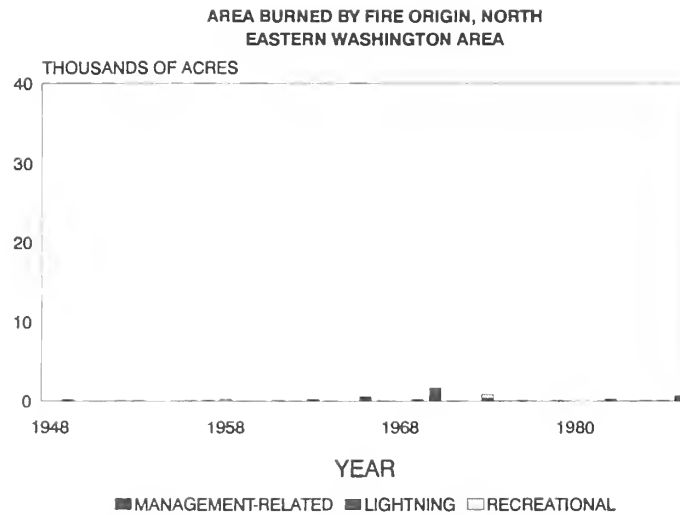


Figure 8A. Area burned in subregions (corresponding to fig. 1) of eastern Washington from 1948 to 1986. Fires were more frequent, but not as catastrophic in drier, southern areas. Northeastern Washington probably had few fires because much of this area was burned in the 1920s. ("Management-related" refers to escaped slash disposal burns, equipment-started, and railroad-started fires; "Recreational" includes campfires and smoking-caused fires.) (USDA Forest Service 1948-86)

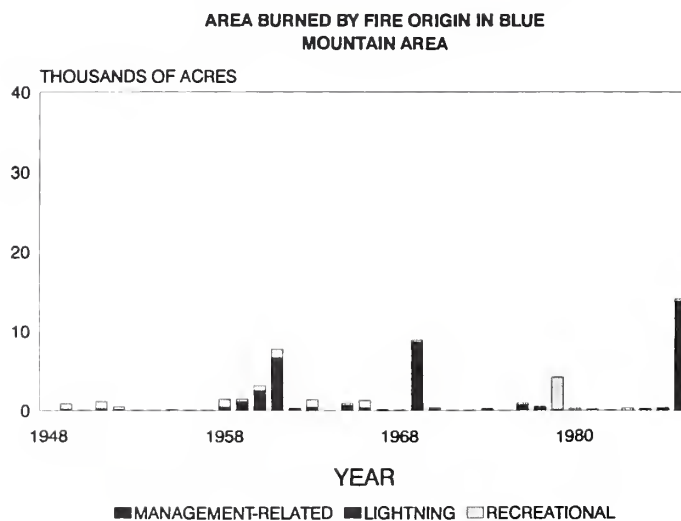
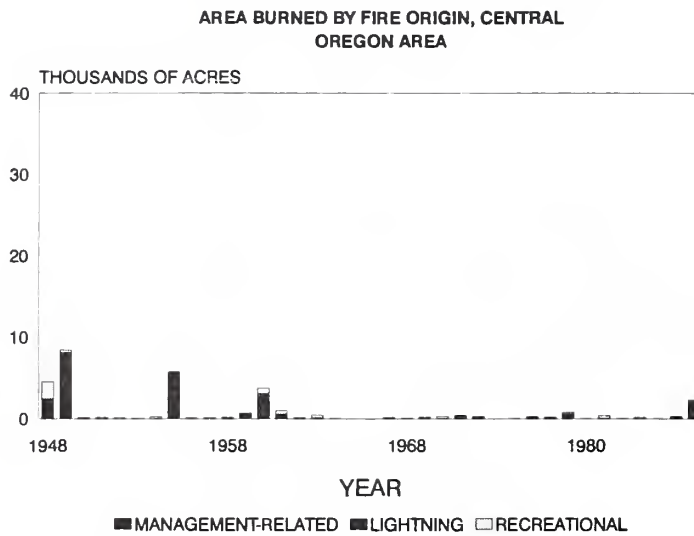
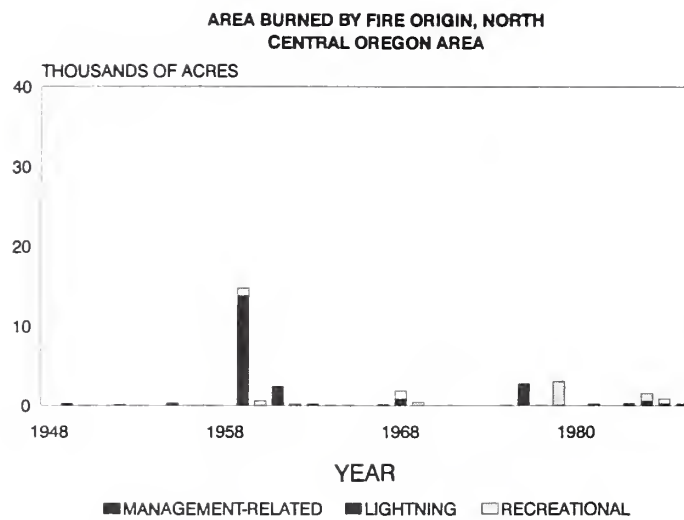


Figure 8B. Area burned in subregions (corresponding to fig. 1) of eastern Oregon from 1948 to 1986. Fires were more frequent, but not as catastrophic in drier, southern areas. Northeastern Washington probably had few fires because much of this area was burned in the 1920s. ("Management-related" refers to escaped slash disposal burns, equipment-started, and railroad-started fires; "Recreational" includes campfires and smoking-caused fires.) (USDA Forest Service 1948-86).

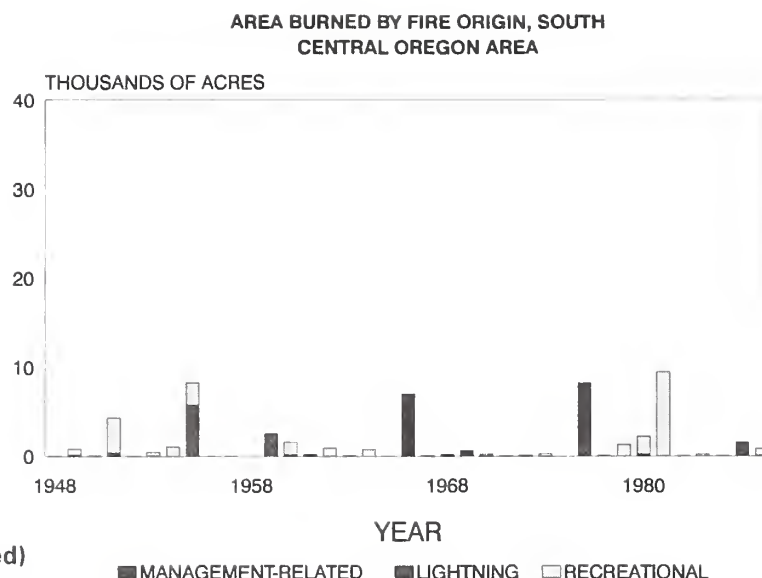


Figure 8B (continued)

Table 4. Cumulative total and percent of area burned between 1948 and 1986. (from USDA Forest Service 1948-1986).

SUBAREA (Table 1)	AREA OF NAT. FOR.	AREA BURNED 1945-1986	% OF TOTAL N. FOR. AREA	EST. FIRE RETURN INT.
N.E. Wash.	1,028,162	6,360	1	6,300 yr.
N.C. Wash.	1,536,958	58,420	4	1,000 yr.
S.C. Wash.	1,908,006	211,955	0	350 yr.
N.C. Oreg.	1,852,497	39,807	2	1,800 yr.
S.C. Oreg.	2,811,379	57,244	2	1,900 yr.
Cent. Oreg.	2,520,069	43,650	2	2,250 yr.
Blu. Mtn.	3,902,252	237,728	6	650 yr.

1Estimated fire return interval" assumed area burned between 1945 and 1986 is normal for 39-year period. In fact, fire return interval is much shorter; therefore, fires were (and will be) more frequent in long term.

Fire prevention allowed fuel buildup and development of dense stands susceptible to bark beetle attacks (Hessburg and others 1993), which in turn created more dry fuels and greater fire risk. Prevention of small fires may result in large, uncontrolled fires such as the ones in 1970 that burned in south-central Washington, north-central Washington, and Canada (fig. 8).

1960 to the Present—Since 1945, an average of about 9500 acres have burned annually in eastern Oregon and about 7000 acres in eastern Washington within National Forest boundaries (table 4), but these wildfires have not occurred regularly or evenly across landscapes; some years had essentially no fires; in others, vast areas burned (fig. 8). In the 40 years 1946-1986, between 0.6 percent and 11 percent of each subarea (fig. 1) of eastern Oregon and Washington has burned (table 4). If these low burning rates are to be maintained, eastern Oregon and Washington are presently on fire "cycles" of 6300 years in northeastern Washington, 350 years in south-central Washington, and 640 years in the Blue Mountains—much longer than occurred before fire protection began in the 1930s.

Maintaining this low fire frequency is unlikely without far more intensive effort and investment than is presently applied. Low fire frequency between 1940 and 1985 is partly because of fire suppression and partly because many forest areas burned in the decades before 1940, and so have been resistant to fires until recently. For example, hundreds of thousands of acres of forests burned in northeastern Washington in the 1920s and 1930s, accounting for a reduction in fires there until the 20,000-acre White Mountain fire in 1988.

A call for a reformed burning policy came with the 1963 Leopold Report, the 1964 passage of the Wilderness Act, and from a series of fire ecology conferences organized by the Tall Timbers Research Station from 1962 through 1975. Backers of wilderness legislation noted the beneficial role of fire, but the Tall Timbers Conferences focused on the beneficial role of prescribed fire in various environments. In 1967, the National Park Service revised its policy to encourage more fire, while the Forest Service reaffirmed the 10 a.m. policy for normal fire seasons, but allowed variance for some pre- and post-season fires. In 1971, the basic policy was amended by adding a 10-acre presuppression policy, the goal of which was to plan for the control all fires at no more than 10 acres. But policy also allowed for free-burning prescribed fires in select wilderness areas.

The 10-acre policy resulted in a wild surge of pre-suppression costs (Pyne 1982), but did not effectively reduce the average number of acres burned. With the increased costs, accumulating fuels and new ecological perspectives on fire, the use of prescribed fire began to look more attractive, and a new fire policy alternative was adopted at a Regional Forester Conference in 1977, becoming Forest Service policy in 1978. The revised policy encouraged fire by prescription and provided alternatives to wildfire the suppression if initial attack was unsuccessful. Current Forest Service policy says nothing about 10 a.m. rules or 10-acre minimum incident areas (Chapter 5130, Forest Service Manual).

Preventing wildfires completely is now widely recognized as impossible unless fuels are reduced. Without preventive silvicultural operations such as thinning and prescribed burning, large uncontrolled fires, such as the one in 1970 in south-central Washington, will periodically occur (fig. 8). Increasing human population and concerns about smoke pollution are making burning restrictions tighter which discourages prescribed burning. Even if begun now, a major effort would be needed to minimize current fuels through harvesting, controlled burning, or a combination of practices. With such mitigation activities, natural fires would burn smaller areas with less intensity. Without them the prospect is that fires will be more intense, frequent, and damaging.

Smoke volume and direction can be managed in prescribed fires by using proper timing and ignition techniques. If managed fires are to be used to avoid uncontrolled wildfires, the current restrictive smoke guidelines are likely to need revision

Many factors complicate any attempt to restore fire—legal liability, public suspicion, the removal of smoke, housing developments, the buildup of fuels, and the changed environment itself. Fire exclusion did not, by itself, cause all problems, and fire's return will not, unaided, restore an earlier landscape. Any reintroduction must accompany other practices and it must guard against escaped fires and unrestricted smoke.

Grazing

Pre-1930—Livestock were brought to eastern Oregon and Washington in the 1840s via the Oregon Trail, and cattle herds were well distributed by the 1880s. At that time, many parts of eastern Oregon and Washington were covered with lush grasses. Evidence of extensive range use was observed as early as the 1870s (Gordon and others 1883). Elk were indigenous to the Columbia Basin (McCorquodale 1985), but were not common before 1850. Market and subsistence hunting by European settlers nearly exterminated elk by 1900 (Bailey 1936, Shay 1954).

Sheepherders would make an annual migration with their flocks, following the snow from low elevations in the spring to high elevations in the summer, and back to low elevations in the autumn. Sheep grazing created enmity between the cattle ranchers and sheepherders because the sheepherders were often itinerants and because conventional wisdom held that sheep destroyed the range and streamsides.

The Forest Reserve Act of 1891 resulted in the first Federal regulations on livestock grazing in 1895. New regulations banned sheep grazing on Forest Reserves in the West, except in Oregon and Washington (Coville 1898). As a result, western sheepherders brought their herds to the Northwest (Carter 1990). As early as 1898, the National Academy of Sciences (1898) judged that such unregulated grazing led to widespread destruction of forage resources.

Livestock grazing on National Forests was sanctioned after creation of the Forest Service by the Transfer Act of 1905 (USDA Forest Service 1905). From 1903 to 1914, sheep and cattle ranchers supported range regulations, including fencing to protect range from overuse (Steen 1976). Grazing fees and other regulations were established in 1906. Little enforcement was possible, however, and livestock routinely trespassed on mountain summer ranges. Political pressure by powerful stockmen kept grazing fees on National Forests low, thereby severely reducing cash flow from range management, and subsidizing grazing.

Grazing was a primary issue of management. In 1907, 80 percent of the receipts from eastern Oregon National Forests and 40 percent from eastern Washington National Forests were from grazing; most of the rest was from timber sales (USDA Forest Service 1908). The Colville National Forest showed no receipts for this period. Sheepherders followed the large fires into north-central (1890s and 1900s) and northeastern Washington (1920s), where sheep could graze on young stands in the newly created "stand initiation" stage (fig. 2) after the fires.

Figure 6 shows trends in the number of sheep, cattle, and horses in Washington and Oregon counties from 1880 to 1990 (U.S. Bureau of the Census 1890-1990). The data are from census reports for agriculture and do not necessarily indicate numbers of livestock grazed on National Forests. Tables 3A and 3B, and figure 5 show similar trends in selected river basins. Production of domestic sheep generally peaked in eastern Oregon counties between the 1890s and the 1920s, and peaked in eastern Washington counties about 1930 (fig. 7). Tucker (1968) and Forest Service records provided a history of the Wallowa-Whitman National Forest, where livestock use declined by 70 percent from 1911 to 1945. Horses declined in all areas after 1920, as a result of increased use of automobiles.

Technical studies that supported management of Federal grazing allotments began in 1907 (Strickler 1980). The number of livestock grazed on National Forests increased slightly after World War I, reflecting a policy change to increased food production. The new policy led to abusive grazing practices, and the Forest Service allowed stocking "to the most optimistically accepted carrying capacity" (Mortensen 1978, cited in Carter 1990).

Heavy grazing resulted in:

- ☐ A general decline in range conditions in eastern Washington and Oregon.
- ☐ Excessive use of forage by 1909 on the Cle Elum Ridge area of the Wenatchee National Forest (USDA Forest Service 1909, cited in Carter 1990).
- ☐ Feuds among sheep and cattle producers over the dwindling forage resources.
- ☐ Removal of highly flammable fuels in some areas, reducing the ground fires that had previously controlled establishment of dense stands of tree seedlings (Hall 1977).
- ☐ Setting of fires by sheepherders and cattlemen that spread to other areas.
- ☐ Establishment of non-native plants, including noxious weeds in some areas, at least partly as a consequence of high stocking rates and associated loss of stable vegetation cover.
- ☐ Siltation of streams and reservoirs.

On the other hand, a thriving wool and meat economy had developed in eastern Washington and Oregon.

1930 to 1960—Several factors combined to dramatically change grazing practices on National Forests. The Dust Bowl and overgrazing made everyone more concerned with regulating grazing, and the Taylor Grazing Act of 1934 gave authority to the USDA Bureau of Land Management to regulate grazing on public rangelands. This law resulted in establishing districts, which coordinated with Forest Service grazing allotments; it also continued to keep grazing fees low. Later, the Granger-Thye Act of 1950 recognized grazing as an official use of National Forests and put the Forest Service in charge of range management.

Sheep herding was more difficult because of range wars, a declining price of wool, fences that restricted herd movements, government subsidies to kill sheep and thereby reduce overproduction, and policies by the King of Spain that increased the costs of keeping Basque shepherds. In addition, a report to Congress in 1935 showed that forage depletion had occurred on most mountain summer ranges in the West (U.S. Senate 1936).

To stabilize Midwest soils in the 1930s, Asian grasses were introduced to rangelands. These grasses were soon introduced to eastern Oregon and Washington as well. Mule deer and elk populations increased as a result of protection and conservative hunting. Hunting for bull elk was authorized in Oregon in 1933, and females became legal game animals in 1939 after 30 years of protection.

The total number of sheep declined dramatically during the 1930s (fig. 6) in eastern Oregon and Washington. The number of sheep in the Yakima River basin declined faster than the area grazed, indicating less grazing pressure on the land; however, the number of sheep in counties of the Blue Mountains continued to be high (tables 3A, 3B; figs. 5, 6).

The number of cattle in eastern Oregon and Washington increased during this period, as did both the number and acres grazed in the Grande Ronde River basin (tables 3A, 3B; fig. 5). The number of cattle in the Yakima River basin declined at a greater rate than the acres grazed, indicating a decline in grazing pressure (tables 3A, 3B; fig. 5).

Decline in grazing pressure allowed some rangeland recovery, although various intentionally and unintentionally introduced grasses grew in many areas, with both positive and negative effects. The effect of grazing on nutrient cycling is unclear, though it has apparently created nutrient shortages in some areas. Less grazing and fewer fires allowed forests to encroach on rangelands (Lehmkuhl and others 1993) and contributed to the development of dense understories of trees in previously parklike stands (fig. 4b).

1960 to the Present—Recent legislation has promoted stronger application of scientific principles for improving rangelands. The Rangelands Renewable Resources Planning Act of 1974 required the Forest Service to offer an assessment of renewable resources every five years beginning in 1975 (Rowley 1985). It also mandated that 50 percent of the fees from livestock use on public lands were to go toward rangeland improvements. The Federal Land Policy and Management Act of 1976 (FLPMA) provided funding for environmental impact statements for livestock grazing in the 11 Western States. The FLPMA also provided for a range-improvement fund, giving grazing on public lands a more secure tenure (Rowley 1985). The Public Rangelands Improvement Act (PRIA) of 1978 developed a stewardship program for combined management of large pilot projects on National Forests and BLM lands. The PRIA also authorized \$2 billion for range improvements over the next 20 years. Another 1978 bill, the Forest and Rangelands Renewable Resources Act, authorized USDA research to be conducted on renewable resources (Joyce 1989).

Recently, elk populations have expanded (tables 3A, 3B) into areas where elk had not been common or abundant for at least 100 years, such as the arid lands reserve in central Washington (McCorquodale 1985). Forests have recently adopted recommendations for winter and summer thermal cover to enhance elk

distribution (Thomas 1979) and to reduce harassment from heavy recreational use (Skovlin 1982). Habitat effectiveness models (Thomas and others 1988a, 1988b) are now standard for predicting the consequences to elk from forest management alternatives.

Livestock on National Forest allotments in the Pacific Northwest have increased since 1969, primarily as a result of an increase of about 30 percent in permitted cattle use (Joyce 1989: 42; see also tables 3A, 3B); permitted sheep use declined sharply. Livestock use on the Wallowa-Whitman National Forest did not change so dramatically.

Range research after 1960 determined proper seasons of livestock use, developed grazing systems, and set appropriate stocking rates for various ecosystems (Skovlin and others 1976, Svejcar and Vavra 1985). For example, in 1950, fewer than 20 percent of National Forest cattle allotments in eastern Oregon and Washington were managed by systems other than season-long grazing. By 1970, over 60 percent of Federal allotments were managed by deferred rotation systems. Recent research has determined appropriate livestock grazing systems for riparian and wetland habitats (Gillen and others 1985, Kauffman 1982, Skovlin 1984).

Application of scientific recommendations has partially restored some rangelands that had been abused (Reid and others 1980, Reid and others 1991, Strickler 1969, Strickler and Hall 1980). The Wallowa-Whitman National Forest (1980, 1981) recently found that rangelands in allotments in two wildlife management units were generally in satisfactory condition. Many allotments in the Snake River and Chesnimnus units were in unsatisfactory and declining condition, a result of poor livestock management practices before the National Forest was established.

Management of big game populations traditionally kept densities low relative to the capacity of habitat to provide nutritional forage (Thomas and Toweill 1982); however, mule deer populations declined precipitously in the 1960s and early 1970s in eastern Washington and Oregon, similar to patterns in other Western States (Schommer 1991, Workman and Low 1976). Conservative harvests have been instituted, and mule deer populations have not rebounded and continue to show low fawn production in many populations.

Rocky Mountain elk populations increased significantly between 1960 and 1981 in eastern Oregon (Edwards 1992, tables 3A, 3B). Population estimates indicated that the aggregate winter population for 20 management units in northeastern Oregon rose to 58,500 (ODFW 1982). Elk populations in southeastern Washington numbered about 24,000. Oregon adopted management objectives in 1981 that limited the size of some populations. Current elk populations may be as high or higher than any time in history.

Hunter numbers increased with increasing elk populations, and concerns about overharvest led to limited-entry permit hunts for elk in the early 1970s. Concern has also grown regarding vulnerability of elk to hunting, which is influenced by increased hunter access through road building, loss of security cover because of timber harvesting (Christensen and others 1991), and high densities of hunters (Vales and others 1991). As elk populations increased, private landowners complained about damage to their lands (Vavra 1980). On the other hand, wildlife biologists are concerned about heavy livestock use on big game winter ranges in summer and fall (Gowan and others 1989). At some point, an acceptable tradeoff and objectives will be set for productivity of elk herds and cattle in relation to objectives for vegetation composition and productivity.

Mining

Pre-1930—Mining activities peaked at different times on the eastside between 1850 and the present (U.S. Bureau of the Census). Gold and silver mining were prevalent in north-central and northeast Washington in the late 1800s. Mining was prevalent in the Yakima (south-central Washington) and Grande Ronde (Blue Mountains) River basins in the early 20th century (tables 3A, 3B). The Forest Service could not prohibit mining or prospecting, according to the 1902 Manual on Administrative Procedures (U.S. Department of the Interior; Steen 1976).

The extent of early mining was variable. The Yakima and Grande Ronde basin samples show mining before 1920 affecting less than 0.6 percent of the area (tables 3A, 3B). Mining near streams, as in the Yakima River basin (tables 3A, 3B), created problems where running water was used in mining. The result was extreme siltation of streams (Wissmar and others 1993).

1930 to 1960—Mining activities fluctuated during this period, although extensive stream diversion projects aimed at moving mining waste diminished. As road construction increased, gravel was taken from stream and river beds, creating turbid water conditions that adversely affected fish populations (Wissmar and others 1993).

1960 to the Present—Mining is still relatively uncontrolled in National Forests. The 1955 Multiple Use Mining Act returns surface rights of claims to the National Forest unless the claim is proved valid (Steen 1976); however, little regulation is done of the mining itself. Mining effects are addressed by the National Environmental Policy Act.

Mining increased in both subsampled basins in recent years (tables 3A, 3B). Chemical mining (for example, using cyanide with gold mining) has increased concerns about ecosystem hazards. Gravel mining of streams for road-building materials is more restricted to minimize the extreme degradation of fish habitats (Wissmar and others 1993).

Timber Harvest

Pre-1930—Early timber harvest was in accessible areas near settlements, mines, and railroads. Large ponderosa pine and some Douglas-fir were harvested because of their fine wood qualities and the abundance in parklike stands at low elevations.

Timber was to be protected and grown “on land unfit for agriculture,” according to the *1902 Manual on Administrative Procedures* (U.S. Department of the Interior, Steen 1976). Specific guides were established for allowing private individuals to harvest timber and for selling it to timber companies.

In 1906, in lieu of paying taxes, 10 percent of the receipts from National Forests were to be returned to the States to benefit public roads and schools. The amount was increased to 25 percent in 1908 (Steen 1976). As National Forest receipts increasingly came from timber revenue, greater incentive was created for local communities to encourage timber harvest. Other values, goods, and services that are currently provided free to the public by the National Forest do not generate receipts or this rate of income to local schools and roads.

Harvest systems—Both uneven-aged methods (selective cutting and high grading) and overstory removal were used in eastern Washington and Oregon. Forests were layered, either because they comprised several fire- or harvest-related age classes, or they were single cohort (even-aged), stratified, and well-differentiated. Both overstory removal and uneven-aged management promoted shade-tolerant species (Agee 1993, Hessburg and others 1993, Johnson and others 1993, Lehmkuhl and others 1993).

Foresters often marked trees susceptible to insect attack for removal, resulting in selective harvesting and overstory removal. Foresters were also occupied with keeping loggers from destroying the forests through their logging practices, although the foresters were often unsure what the best practices were. The lack of silvicultural knowledge was recognized, and many forestry guides were promoted, (for example, Carter 1908; cited from Mustian 1976), as temporary solutions until the foresters could gain more knowledge. Foresters vacillated between promoting even-aged management (shelterwood, seed tree, clearcutting, and overstory removal cutting methods) and uneven-aged management through selective cutting. As much as possible, foresters discouraged uneven-aged “high-grade” logging practices, which were most economical for timber companies. A relatively minor volume of timber was removed during this period compared with later periods.

Equipment—Railroad logging was not done in many places in eastern Oregon and Washington because high timber volumes per acre were needed to pay for their installation (Williams 1989). Spur railroads were developed in parts of the Blue Mountains, and ox teams yarded logs to these spurs (Skovlin 1991). Small-gauge railroads in south-central Washington also suggest that some railroad logging was done there (USDA Forest Service 1908). Logging was sometimes done with splash dams, streams were temporarily dammed, the resulting reservoirs filled with logs, and the dams were opened to allow the logs to flow downstream with the ensuing flood (Skovlin 1991). Such practices severely altered streams and riparian zones.

Post-harvest fuel treatment—Although controlled slash burning was practiced by the Forest Service in western Washington and Oregon during this period, the few clearcut stands in eastern Washington and Oregon (tables 3A, 3B) did not allow as much opportunity for controlled burning. This lack of burning to reduce logging slash, combined with dry growing seasons and slow rates of decay, produced the current high fuel loads.

1930 to 1960—Because trucks made trees easier to get to (fig. 9), and the newly invented chainsaw made cutting trees down easier, timber harvest increased in eastern Oregon and Washington during the late 1940s and early 1950s (fig. 10). Timber harvest increased in part to meet the demand for new housing after World War II. Timber harvest increased dramatically in this period (tables 3A, 3B; fig. 10), with only a small decline in total conifer growing stock (fig. 11). Harvesting reduced tree mortality from other causes also abundant at that time (fig. 11). At first, ponderosa pine and Douglas-fir were harvested; later, as these species became less abundant, other species in middle and upper elevations, including grand fir, white fir, lodgepole pine, and western larch, were harvested (fig. 10, Hooser and Keegan 1985). Once the largest trees had been harvested, progressively smaller trees were used. The effect was to reduce the numbers of large diameter trees (fig. 10).

Harvest systems—Forest managers continued to be concerned about proper ways to harvest the many and varied stands (Moss 1953, Rapraeger 1940, Weidman 1936). Ecological theory of the day emphasized stable forests, free of large disturbances, growing naturally to a climax condition of tolerant species. Uneven-aged harvesting was promoted in western Washington and elsewhere in the 1930s and 1940s, but by the mid-1950s, even-aged management was considered more biologically appropriate and simpler to administer since the weak, diseased, and injured trees were not left after the harvesting and the newly regenerated trees grew most vigorously in the full sunlight provided by the clearcut.

In the early part of the period, most harvesting was still done using overstory removal or uneven-aged cutting methods (tables 3A, 3B; fig. 12) because of the multiple canopy layers and irregular nature of stands (fig. 4). With selection cutting, many acres were entered with relatively little total volume removed (for example, compare the acres harvested between 1921 and 1945 with the acres harvested in the Yakima River basin (tables 3A, 3B). The effect of uneven-aged cutting was to promote multiple canopy layers further and to encourage a lower stratum of shade-tolerant trees in areas where shade-intolerant and fire-

tolerant species had previously grown. In other areas, dense stands of small trees were established where large fires of the late 19th and early 20th centuries had occurred. By this time, it was becoming obvious that fewer parklike stands were in the stand initiation stage (fig. 4).

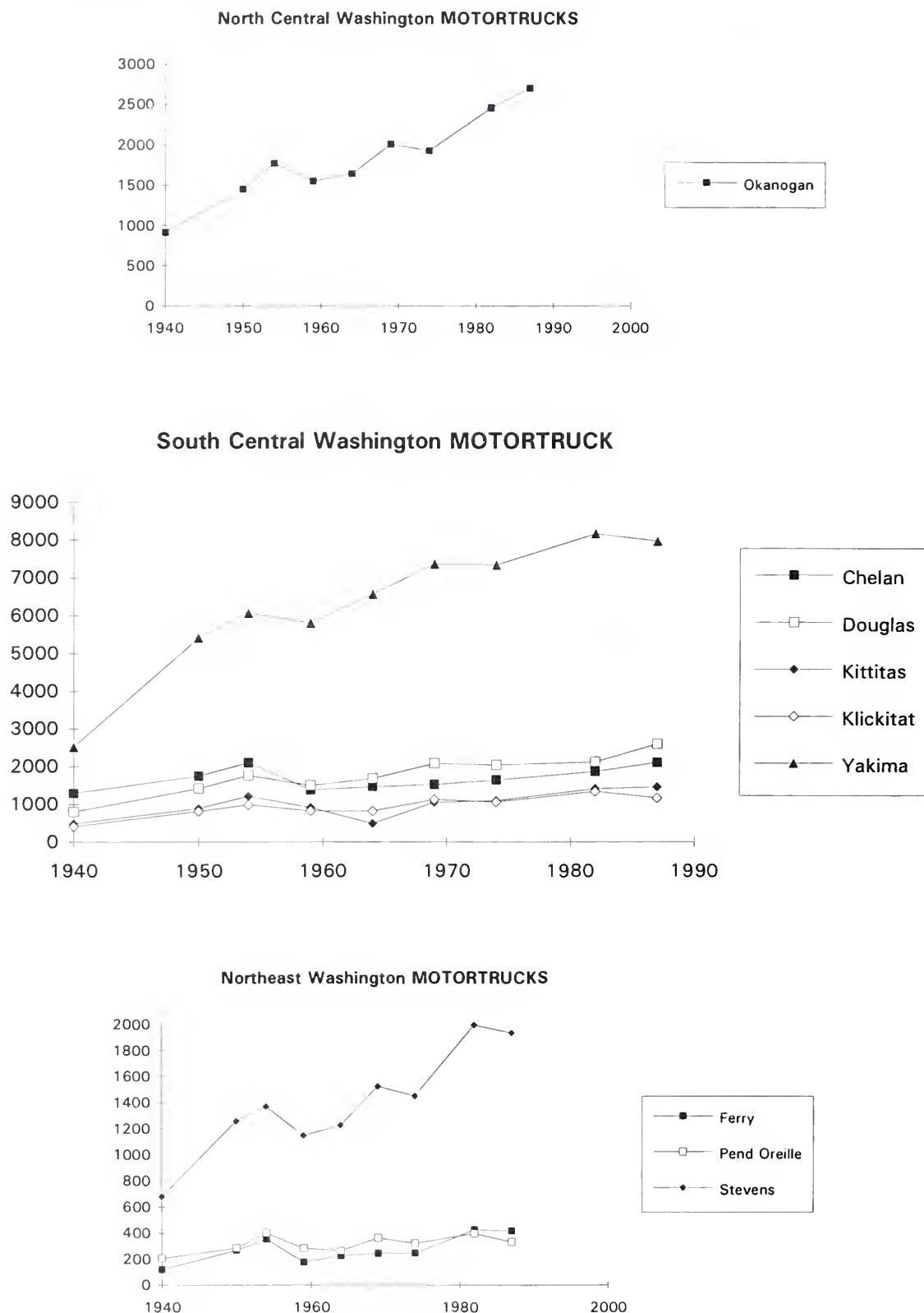
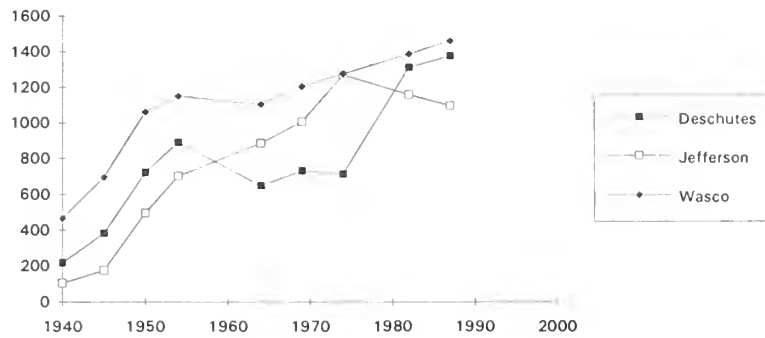
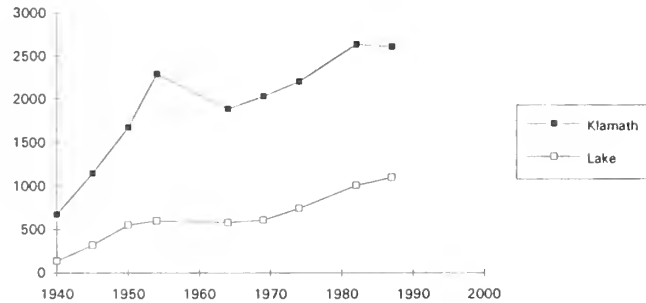


Figure 9A. Motortrucks increased dramatically in eastern Washington, increasing the ability to log previously inaccessible areas. (U.S. Bureau of the Census)

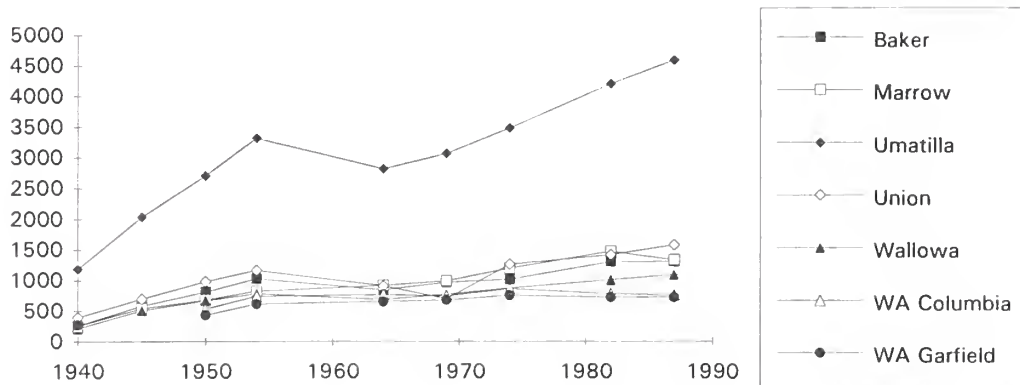
North Central Oregon MOTORTRUCKS-PICKUPS



South Central Oregon MOTORTRUCKS-PICKUPS



Blue Mountains MOTORTRUCKS-PICKUPS



Central Oregon MOTORTRUCKS-PICKUPS

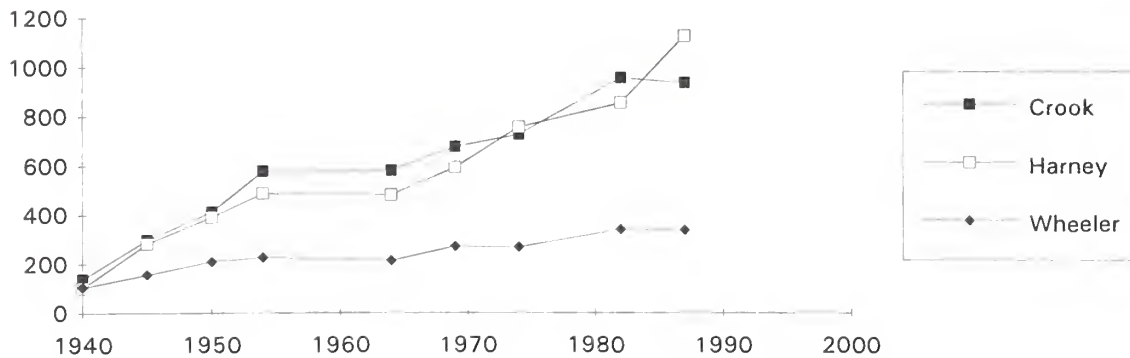


Figure 9B. Motortrucks increased dramatically in eastern Oregon (9B), increasing the ability to log previously inaccessible areas. (U.S. Bureau of the Census)

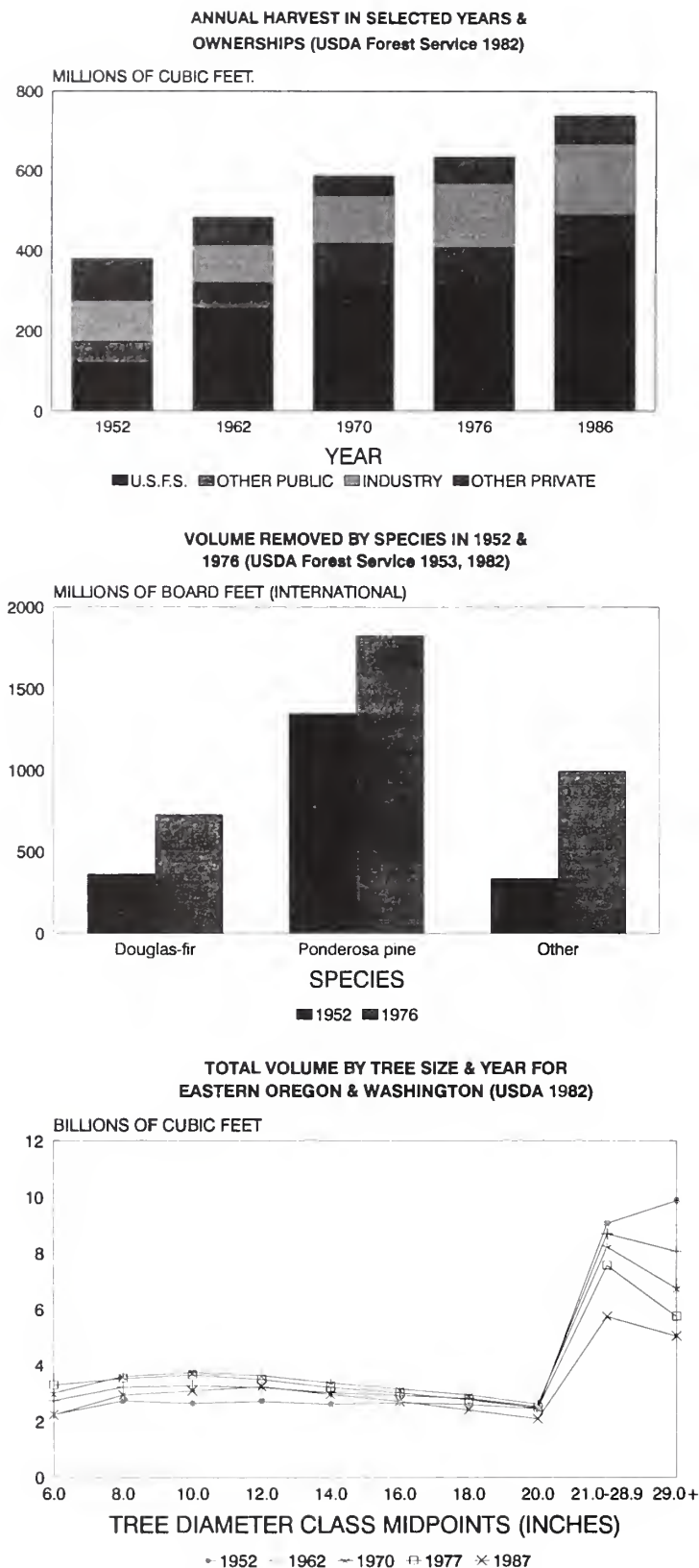
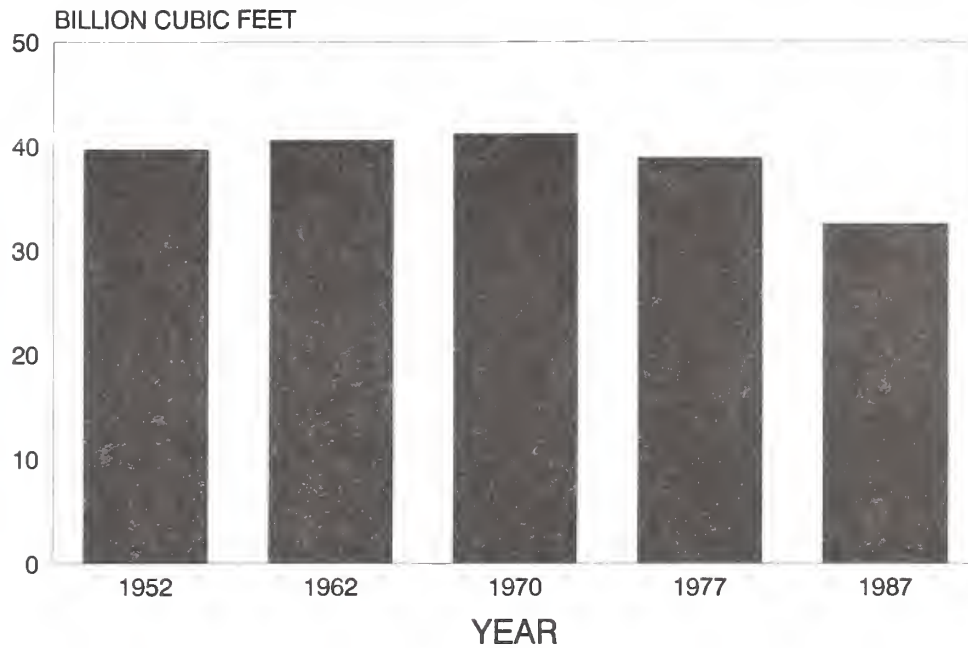


Figure 10. (10A): Timber harvest has increased since 1950 on nearly all ownerships in eastern Oregon and Washington. 10B: Early harvest was of ponderosa pine, then Douglas-fir; more recently, true firs, lodgepole pines, and others have been cut as well—as areas with these species became accessible and as available stands of ponderosa pine and Douglas-fir were reduced. 10C: Trees became smaller and stands became more crowded in eastern Oregon and Washington as larger trees were harvested and then succeed by crowded stands of small diameter not thinned by fires or silvicultural operations. (USDA Forest Service 1982, Waddell and others. 1989)

NET VOLUME OF CONIFER GROWING STOCK IN EASTERN OREGON AND WASHINGTON



ANNUAL MORTALITY IN SELECTED YEARS & OWNERSHIPS (USDA Forest Service 1982)

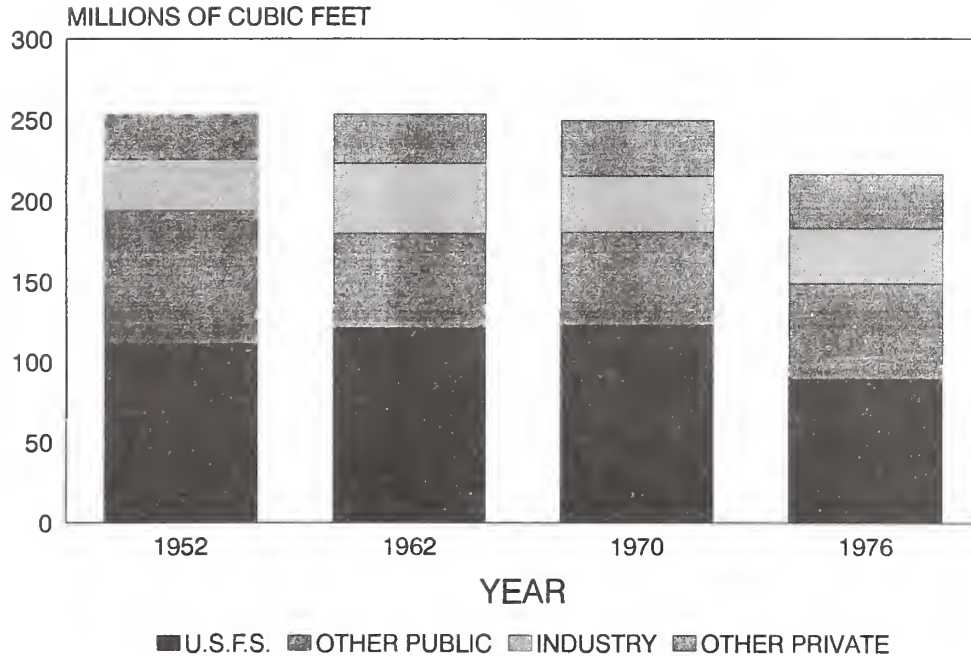


Figure 11. The volume (A) and mortality (B) of trees in eastern Washington and Oregon have been reduced since 1950 by increased timber harvest (USDA Forest Service 1982, Waddell and others 1989).

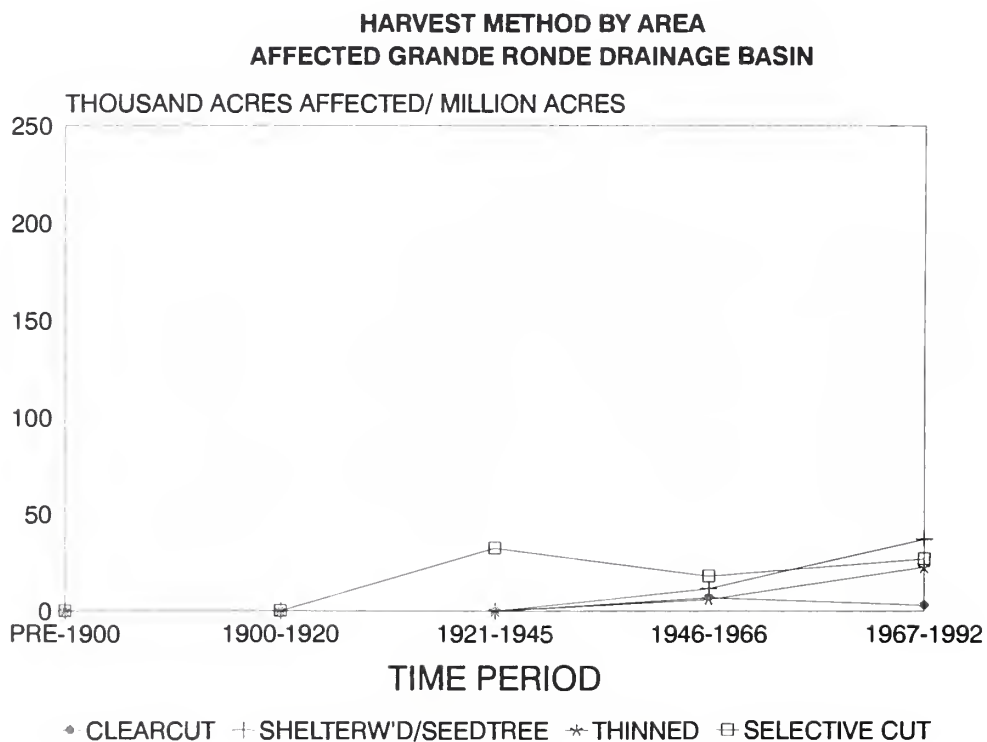
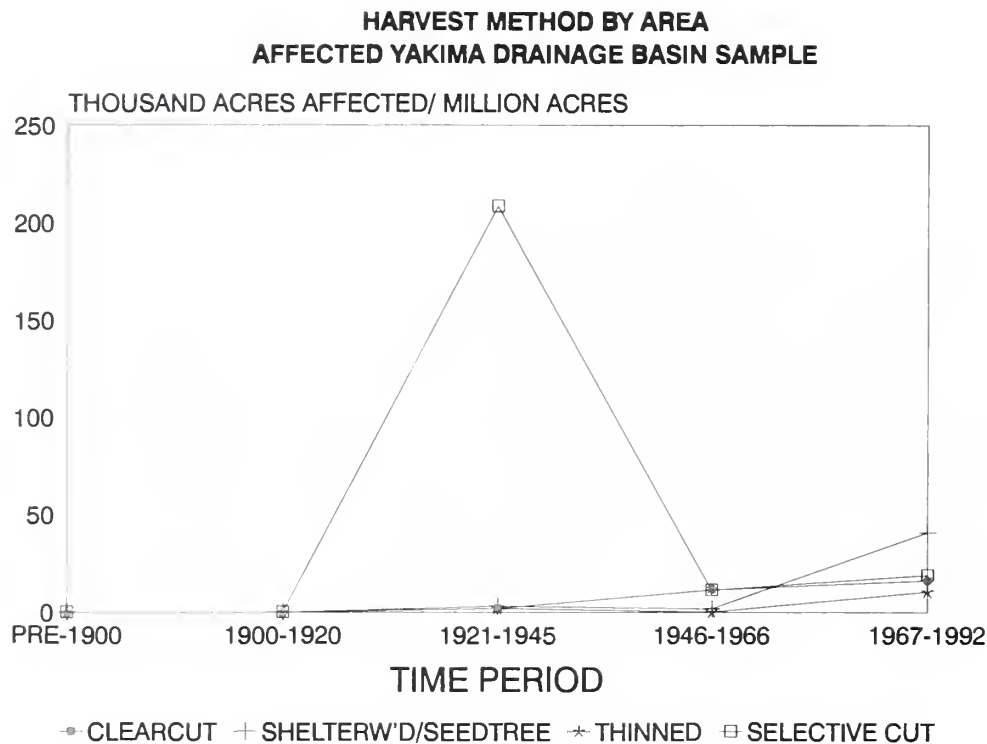


Figure 12A & 12B. Early harvesting generally consisted of selective cutting of stands. Because only large trees and few species were used, early logging often consisted of selectively removing the large trees (fig. 4) and leaving vigorous trees ("silvicultural selection cutting") or leaving weak, low vigor trees susceptible to diseases ("high grading" by loggers). Now, shelterwood and seed-tree harvesting are most prevalent, creating parklike stands of figure 4. Clearcutting and selective cutting are less common. (Overstory removal is probably included with selective cutting.)

Equipment—Technological advances in belt tractors (for example, Caterpillars and crawler-tractors) in the 1930s and in automobiles and trucks in the 1940s allowed machines to do the work people used to do on farms and in the woods (U.S. Bureau of Census). Tractor logging using crawler-tractors to yard logs increased dramatically during this period (tables 3A, 3B).

Post-harvest fuel treatment--The 1943 ruling that allowed broadcast burning did not affect stands in eastern Oregon and Washington to any major degree because these stands were still almost entirely selectively logged or thinned (overstory removal).

1960 to the Present—Timber management from 1960 until very recently has been dominated by concerns of an “impending timber shortage” (Oliver 1986), increased harvesting rates in eastern Washington and Oregon (fig. 10), harvesting of small-diameter trees, and more varied species (fig. 10), intensive management practices, increased risks from diseases, insects, and fires (Hessburg and others 1993), and greater public involvement and distrust. The amount of timber harvested has differed greatly between subregions (fig. 13).

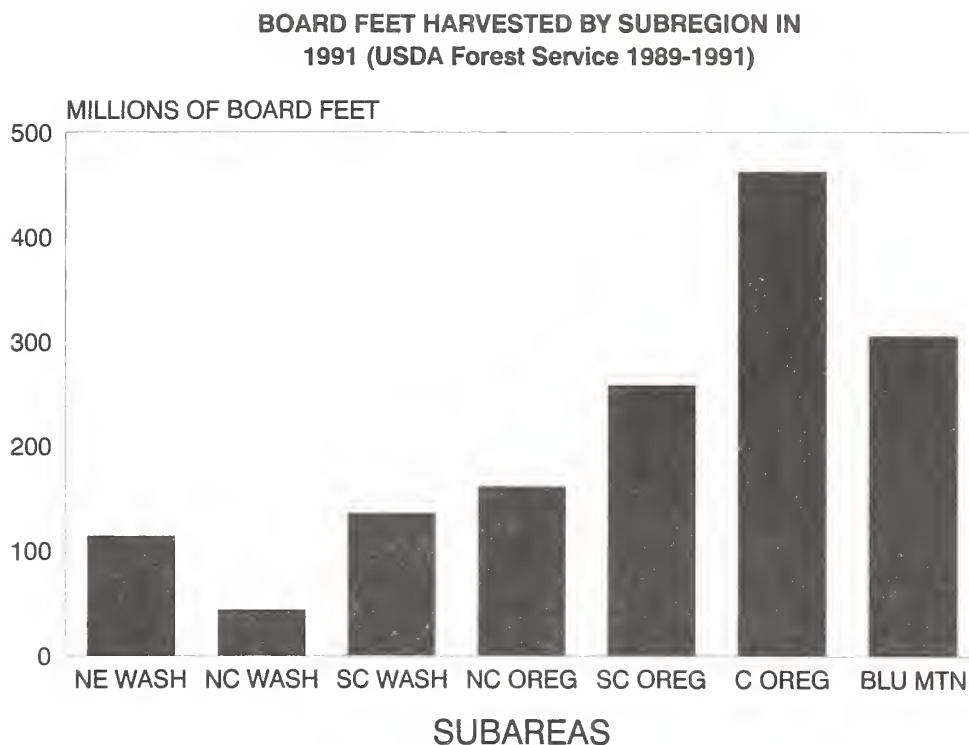


Figure 13. The amount of harvest varied among regions in 1991 (USDA Forest Service 1989-91).

Harvest systems—By the early 1960s, even-aged (single cohort) management including clearcutting was accepted among foresters as a biologically and economically acceptable management technique. Foresters continued to manage most stands in eastern Washington and Oregon with overstory removal, selection, shelterwood, or seed tree systems (fig. 12). Although these treatments could be termed even-aged, where the effect was to leave standing trees after harvest, the resulting stands often grew more like multiple cohort (uneven-aged) stands, with the multiple canopy layers, diseased residual trees, and favoring of shade-tolerant true firs species. As a result of these harvesting practices and fire protection, relatively few stand initiation areas, favoring species utilizing these areas, have been created in the past few decades. A very high proportion of stands on non-Federal lands in eastern Washington was also managed with

overstory removal, selection, seed tree, or shelterwood systems (CINTRAFOR 1993). Where scattered overstory trees remained, these areas were commonly treated with an overstory removal cut. Sometimes selective harvesting was still done because foresters knew they could not regenerate an area using even-aged cutting methods.

Loggers sometimes defined clearcutting as removing the merchantable trees—leaving unmerchantable trees and in effect creating a high graded stand—“cutting the best, leaving the rest.” In response, foresters termed this “commercial clearcutting” and recommended “silvicultural clearcutting” or “cleancutting,” in which the unmerchantable stems were felled to allow a vigorous stand to regrow. At times, some foresters had to be reminded that clearcutting may not always be the only or best way to manage forests (Franklin and DeBell 1973). As foresters became comfortable with clearcutting, society was becoming concerned with it. Unsightly clearcuts on the Bitterroot National Forest (Burk 1970) and the Monongahela National (Minckler 1973) Forest further aroused public concern and attention to clearcutting. Ecologists of the day questioned the scientific and ecological merits of clearcutting.

Forest harvesting policies have varied in eastern Washington in recent years, with restrictions placed on the sizes of harvesting units and much more consideration given to aesthetic appearances of forest landscapes. Forest management has improved and roads, equipment, and skilled labor has increased dramatically, but at the same time society has become more concerned about endangered species and forest health.

Although timber is one by-product of the management of ecosystems, timber production alone cannot economically justify the silvicultural activities needed in many eastside forest ecosystems to control or prevent catastrophic insect and disease outbreaks, wildfires, and reduction in habitat diversity over large areas. If other values are also considered, such as maintaining or restoring biodiversity; long-term site productivity; habitats; fire, insect, and disease risks; employment, and recreation—active management of eastside ecosystems using a variety of silvicultural techniques could easily be justified (Lippke and Oliver 1993). Analyses such as these are being initiated in forest planning and in the TSPIRS program (USDA Forest Service 1989-1991).

Equipment—During the 1960s, rubber-tired skidders were developed that could rapidly yard trees on gentle terrain (slopes less than 30 percent); however, these machines adversely affected wet soils high in silt or clay. With increasing education and technical experience of forest managers, yarding equipment is now prescribed for specific weather, soil, and terrain.

Yarding equipment and yarding systems are now engineered to minimize soil disturbances. Cable yarding systems are more commonly used in the subsampled river basins in eastern Oregon and Washington (tables 3A, 3B). Helicopters, mechanical shears (feller-bunchers), and other ground-based yarding machines have also been used on a limited basis.

Post-harvest fuel treatment—With improved burning standards, slash is left to rot in place; crushed and chopped and added to the soil; hand or machine piled and left to rot; or hand or machine piled, allowed to dry, and burned in the spring or fall.

Machine piling and burning has been widely practiced since about 1950. It often causes more soil disturbance than the initial logging, volatilizes more nutrients than broadcast burning, concentrates available nutrients and organic material at the location of the burn piles, and concentrates heat transferred to soil beneath the piles.

Extensive fuel loads created by thinning entries temporarily creates an extreme fire hazard, which further discourages foresters from thinning dense stands. Before dense stands are thinned, they are often highly susceptible to fire because of the many small, dead trees. Fire danger is extremely high immediately after

thinning because of the accumulated dead slash on the forest floor; however, fire danger declines several years later as slash rots and the overstory casts more shade, creating moist conditions near the forest floor. The cost of thinning and slash disposal is very high if slash is treated (for example, piled or burned) immediately after thinning.

Early stand spacing with herbicides has been done with moderate success; cool, slow burning ground fires provide better results. Using fire as a thinning tool results in trees with smaller diameters than manual thinning.

Roading and Access Management

Pre-1930—The earliest concerns of Federal land managers were essentially custodial—controlling grazing, illegal timber harvesting, and forest fires. Forest patrols were reported in different parts of eastern Oregon and Washington, with one person patrolling from 100,000 to 200,000 acres in summer, and from 200,000 to 300,000 acres in winter (USDA Forest Service 1908). More access roads and trails were built which were credited with stopping fire spread (Steen 1976). Roads were obtained without direct appropriations—loggers built roads to the harvest units and then deducted the cost from the final payments to the Forest Service. This arrangement began a long practice of allowing timber revenues to pay for, and thus indirectly control, many management practices on National Forests.

By 1907, only 360 miles of road had been built in all of Oregon's National Forests; 147 miles in all of Washington's National Forests (USDA Forest Service 1908). These roads were largely considered privately owned. By 1920, the Yakima River basin contained 176 miles of road per million acres; the Grande Ronde River basin had 287 miles per million acres (tables 3A, 3B). Railroads were also built into some areas, but not others. Increased roading allowed greater access and allowed protection of the forest from fires and catastrophic outbreaks of insects. It also allowed greater inventory of the extent of the resources. Access by recreationists also increased.

1930 to 1960—Attempts to have more direct control over the road network—rather than have it indirectly controlled by timber revenues—were made between 1953 and 1956, when the Chief of the Forest Service asked for direct appropriations for road building (Steen 1976). This direct appropriation would not have cost more than the current method of subtracting costs from timber revenues. The direct appropriation method would have allowed road placement to serve many uses, rather than placement directed by most efficient timber harvest. Road construction in National Forests increased between five- and ten-fold between 1900 and 1966 in the Yakima River and Grande Ronde River basins.

Many early logging roads were poorly constructed and subsequently collapsed. Road failures have been one of the biggest causes of erosion and stream degradation associated with timber harvesting (Seaton and others 1973).

1960 to the Present—Despite some direct appropriations for road construction (pre-roading dollars), most road construction and reconstruction in National Forests is done by logging companies that finance that work through deductions from timber payments (fig. 14). Consequently, taxpayers still pay the full cost of road construction. The decision of where and when to build them, however, hinges on the logistics of timber harvesting.

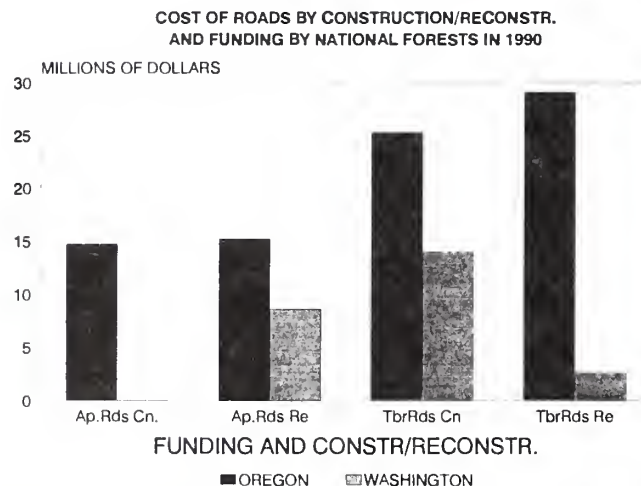
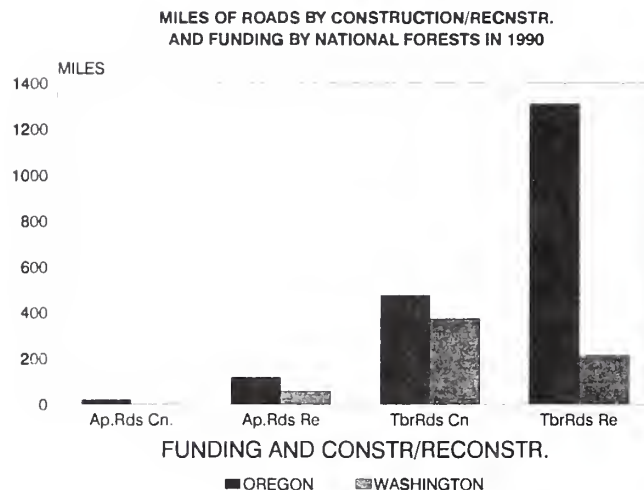
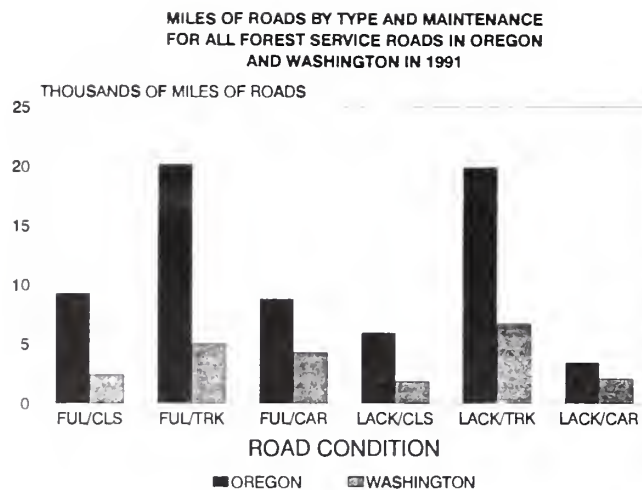


Figure 14. Most Forest Service roads in Oregon and Washington, built and maintained by timber purchasers, are suitable for trucks. Highest costs/mile of roads were from appropriated funds; greatest lengths were by timber purchaser (USDA Forest Service 1975-91). 14A: Miles of U.S. Forest Service roads by type and maintenance for all of Oregon and Washington (eastern and western), 1991. Most roads are high clearance and open; about one half are fully maintained:

FUL/CLS = fully maintained, closed
 FUL/TRK = fully maintained, high clearance
 FUL/CAR = fully maintained, passenger car
 LACK/CLS = lacking full maintenance, closed
 LACK/TRK = lacking full mnt., high clearance
 LACK/CAR = lacking full mnt., passenger car

14B. Total miles of roads.

14C. Total cost of roads.

Ap.Rds.Cn = Constructed from appropriated funds

Ap.Rds.Re = Reconstructed from appropriated funds

TbrRds Cn = Constructed by timber purchaser

TbrRds Re = Reconstructed by timber purchaser

From 1975 to 1991, Oregon and Washington experienced a dramatic increase in road construction. During each of those years, about 1800 miles of roads were built, and 500 miles of roads reconstructed in each state along with about 10 bridges in Oregon and 6 in Washington (USDA Forest Service 1975-91; roading figures for eastern Washington and Oregon were not readily available). This dramatic increase in road construction is reflected in the data from the subsampled watersheds of the Yakima River and Grande Ronde River basins (tables 3A, 3B). Most roads are suitable only for truck traffic (fig. 14).

Pest Management

Pre-1930—Outbreaks of insects occurred before intensive settlement of the interior West (Hessburg and others 1993), although their intensity and duration were probably much less than the fires that periodically erupted.

The Organic Act of 1897 that created the present Forest Service also provided for a mandate to control insect outbreaks. Surveys for mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and western pine beetle (*D. brevicornis* LeConte) occurred as early as 1899, with systematic surveys in south-central Oregon from 1911-20 (Dolph 1967, Miller and Keen 1960). One effective and inexpensive method of controlling beetles was to fell beetle-infested trees and then peel the bark to expose the infested tree to the sun. Another method was to burn beetle-infested trees. In 1908, the first reported major outbreak of the mountain pine beetle in lodgepole pine in the Blue Mountains (Wallowa National Forest) prompted the first bark beetle control project in the Pacific Northwest. Another beetle outbreak struck ponderosa pine in the Blue Mountains (Whitman National Forest). In 1910, thousands of trees were felled and peeled, or burned.

With limited funds, personnel, technology, access, and knowledge, the primary tool for avoiding large scale insect and disease mortality was to harvest infested or susceptible trees. This harvest of infested or weak trees—often not just large, high quality dominant trees in a stand—was in conflict with the interest of timber companies that could profit more by harvesting the large dominant trees and leaving the smaller, weaker ones. Foresters often enforced removing weaker trees and leaving vigorous, upper canopy trees; otherwise, a high-graded stand resulted, with the characteristics described earlier. In both cases, the residual overstory favored the regeneration and release of shade-tolerant conifers where ponderosa pine had previously grown. These shade-tolerant understory trees competed with residual overstory pines for limited water, depressing their vigor, and making them more susceptible to bark beetle attacks. As more pines died and were harvested, shade-tolerant trees grew larger. Resulting stands had multiple layers and were more susceptible to certain defoliating insects (Hessburg and others 1993). Detection of defoliating insects was difficult, and suppression did not occur before aircraft were operationally available after World War II.

Outbreaks of defoliating insects occurred before European settlement (Wickman and others 1993). Between 7 and 10 outbreaks of either western spruce budworm or Douglas-fir tussock moth have been detected in the Blue Mountains since 1790. Budworm outbreaks occurred from 1775-85, 1822-30, 1838-42, 1870-78, and, the most severe of these, from 1898-09. Tussock moth outbreaks occurred from 1843-45, 1852-54, and in 1875. One outbreak killed 300 million board feet of Douglas-fir and grand fir in northeast Washington in 1929-30 (Furniss and Carolin 1977, Gast and others 1991). Minor outbreaks occurred in the Blue Mountains at about the same time.

The pine butterfly was reported attacking ponderosa pine near Spokane in 1882. Between 1893 and 1895 the pine butterfly infested 150,000 acres in south-central Washington (Yakima Indian Reservation) and, with the help of bark beetles, killed 90 percent of infested trees—nearly one billion board feet of timber (Keen 1952).

1930 to 1960—With more human resources and infrastructure, forest managers were becoming more concerned about protecting forests from insects and diseases. State officials and private landowners were encouraged to cooperate in pest-control efforts through the Forest Pest Control Act of 1947 (Steen 1976). Between 1930 and 1960, the Forest Service began conducting aerial surveys of insect outbreaks and issuing periodic reports.

Forest managers devised plans to control mountain pine beetle infestations in lodgepole pine; western pine beetle infestations in ponderosa pine, western spruce budworm and Douglas-fir tussock moth outbreaks in Douglas-fir and grand fir, and white pine blister rust infecting western white pine and sugar pine. Not every plan worked, however. The white pine blister rust pathogen, not native to these forests, was introduced early in the century and quickly decimated the western white pine population.

Large outbreaks of the mountain pine beetle in north-central Oregon (Deschutes National Forest) and in the Blue Mountains lasted from the late 1940s until the mid-1950s. The outbreaks occurred primarily in lodgepole pine in the Cascade Range, and in ponderosa pine in the Blue Mountains. In 1950, 52,000 acres were infested, with 30,000 acres on the Deschutes National Forest. Another 42,000 acres were infested in eastern Washington. "Salvage" logging removed infested trees.

From 1955 to 1966, more than 800,000 acres of lodgepole pine were infested by the mountain pine beetle, with 82 percent of those acres in central Oregon. In Washington, most of the infestation was in the northeastern (Colville National Forest) and north-central (Okanogan National Forest) regions of the State. The emphasis in mountain pine beetle management had been to avoid infestations by maintaining healthy, vigorous stands with regular thinning. In 1960, one chemical control project was completed in southwestern Oregon (Fremont National Forest) in which several thousand trees were sprayed with ethylene dibromide (Dolph 1967, USDA Forest Service 1938-91).

Sanitation and salvage logging for the control of western pine beetles came into general use in the late 1930s. Tree selection was based on the tree "risk rating system" of Keen (1936). Toxic oils and organic insecticides such as DDT were developed during World War II. Major outbreaks of the western pine beetle in 1932 destroyed 1.8 million board feet of timber. As many as 33,800 trees—often large, "yellow-belly" ponderosa pines—were treated (felled-peeled-burned) on public and private ownerships in south-central Oregon. In 1953, western pine beetle outbreaks increased from 303,000 acres in 1951 to more than 1 million acres in south-central Oregon, north-central Oregon, and south-central Washington. The Yakima Indian Reservation had an estimated 200 to 400 dead trees per section (640 acres) during this time. Another outbreak in south-central Washington, north-central Oregon, and the Blue Mountains increased from 16,000 acres in 1956 to 294,300 acres in 1959. Control measures included both sanitation salvage logging as well as ethylene bromide treatments (Miller and Keen 1960).

Outbreaks of the Douglas-fir beetle, usually a problem in western Oregon and Washington, have occurred in eastern Oregon and Washington in trees previously weakened by western spruce budworm. Douglas-fir beetle outbreaks occurred from 1952 to 1954 in the Blue Mountains of north-central Oregon, and south-central Washington, and in northeast Washington from 1955 to 1956 (USDA Forest Service 1938-91). Outbreaks were handled primarily by salvage logging.

From the 1930s to the 1950s, an unsuccessful effort was made to control white pine blister rust in northeastern Washington, Idaho, and Montana by eradicating currant (*Ribes* spp.) plants, the alternate host of the disease (Bingham and others 1972, Matthews and Hutchinson 1948, Moss 1953).

A tussock moth outbreak in 1937 killed large amounts of timber throughout 80,000 acres (Gast and others 1991) and another outbreak in 1946-47 covered 500,000 acres in eastern Oregon and Washington, and northern Idaho. An insect damage control program began in 1947 and included a regionwide aerial survey

and a standardized method of coding severity of defoliation. In 1947, the largest suppression project up to that time was also undertaken; DDT was applied on 15,000 acres of National Forest and private land (Perkins and Dolph 1967) at a rate of 1 pound per gallon of oil per acre. (fig. 15).

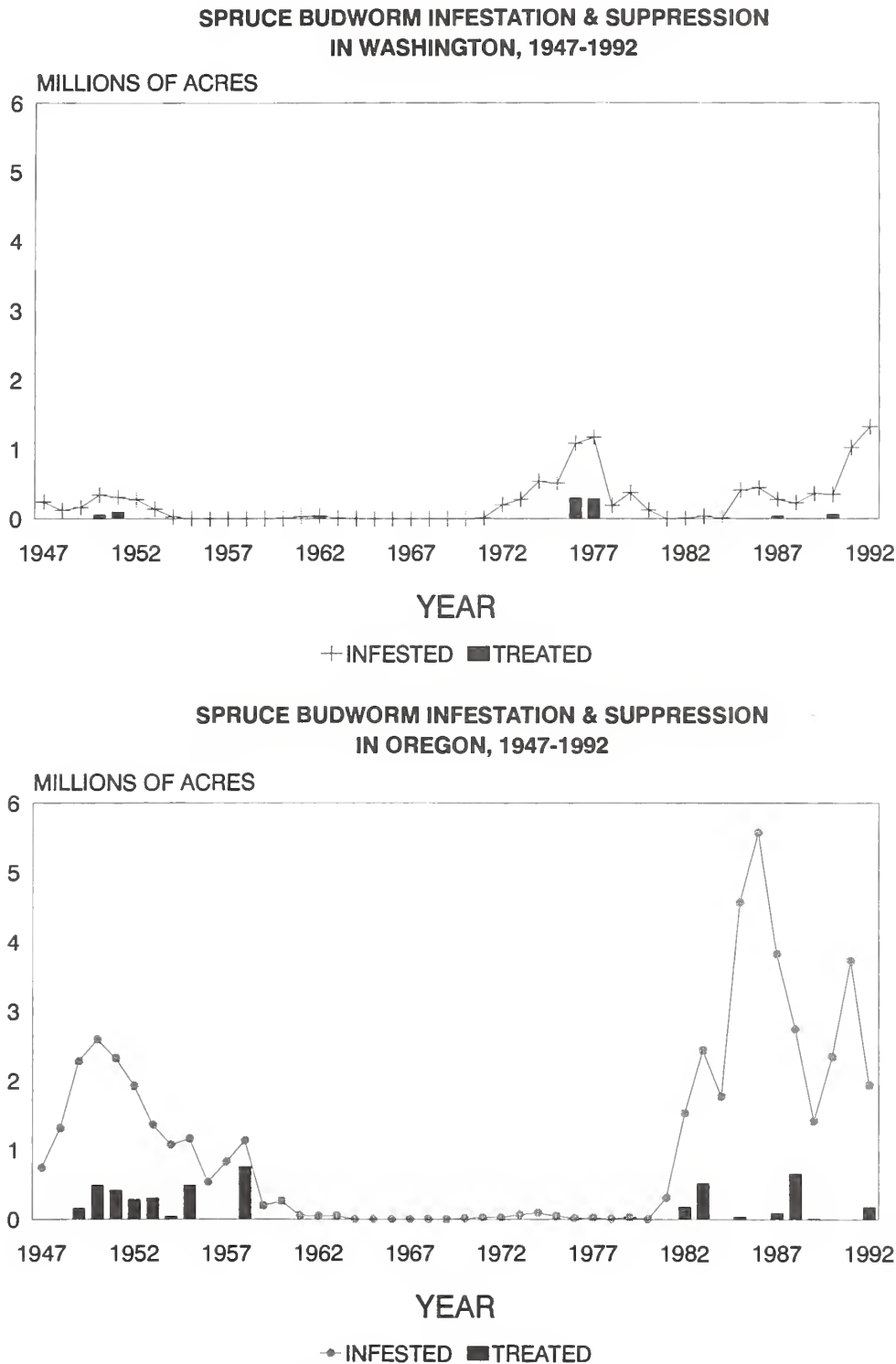
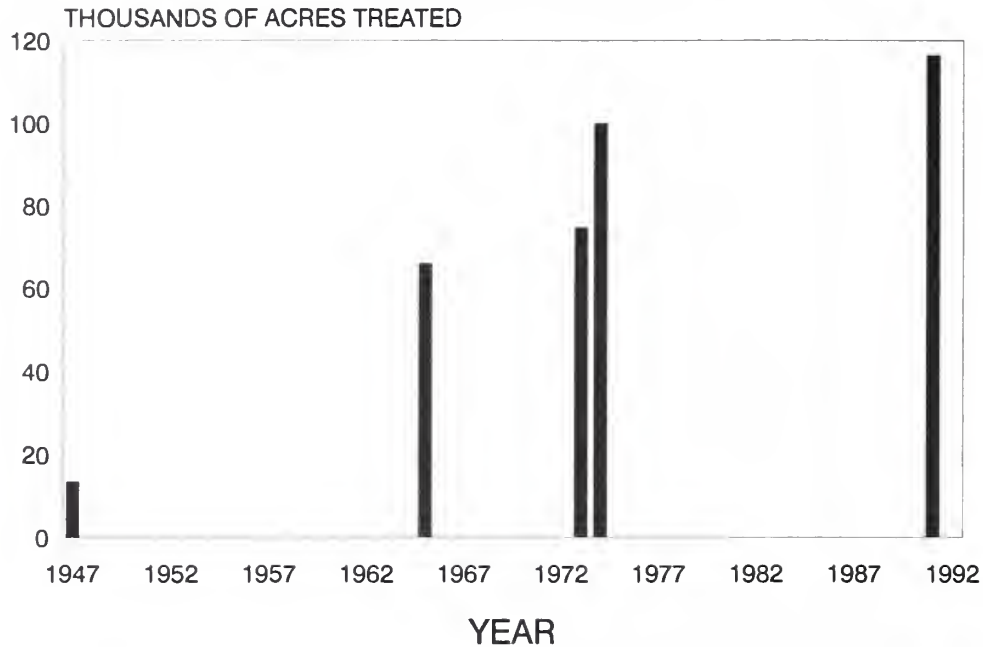


Figure 15. Spruce budworm infestations in eastern Oregon (15A) and Washington (15B) were partly treated with aerial chemical spraying. DDT was used in early sprays. 15C: Most spray programs for tussock moth control have generally been in Oregon. 15D: Recent spray programs for defoliating insects (budworm and tussock moth) have been concentrated in the Blue Mountains, central Oregon, and south-central Washington. (Data from Dolph 1980 and unpublished data, USDA Forest Service, Forest Pest Management Program, Portland, Oregon, 1993)

**DOUGLAS-FIR TUSOCK MOTH CONTROL PROJ.
U.S.F.S. IN OREGON, 1947-1992**



**AREA TREATED FOR SUPPRESSION OF BUDWORM
AND TUSOCK MOTH ON NATIONAL FORESTS,
1982-1992**

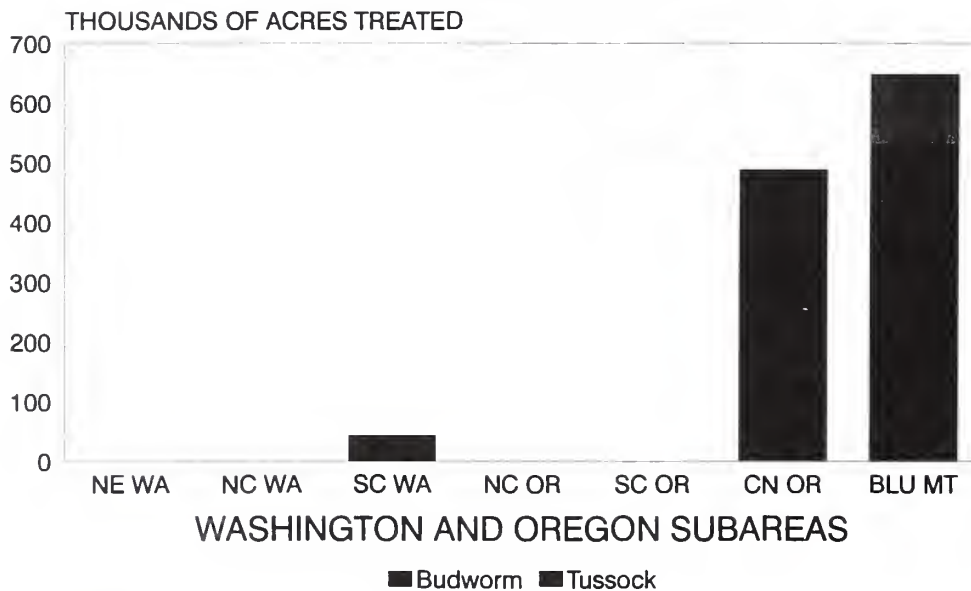


Figure 15 (continued)

Western spruce budworm activity increased in the late 1940s, and one outbreak in eastern Oregon and Washington covered 2,941,744 acres prompting aerial applications of DDT (fig 15). Forests were sprayed for defoliators with DDT throughout most of the 1950s. The number of acres treated for both spruce budworm and tussock moth infestations was far less than the acres infested. Although the treatments were considered a success, how much of the budworm's collapse in the 1950s was caused by spraying and how much was caused by natural mortality is difficult to determine (Dolph 1980).

Aerial spraying seems to have reduced defoliator populations in extreme outbreaks. Outbreaks are recurring, however, because of climate flux and landscape composition and structure, among other things. Because these insects are native to the region, populations will always fluctuate, sometimes causing outbreaks. Past natural and human activities have created forest stand structures which are presently very conducive to insect outbreaks over large areas of eastern Oregon and Washington (Hessburg and others 1993). Silvicultural manipulations, including prescribed fires, can reduce the extent of susceptible stands and thus help lessen outbreak extent and duration, and likely diminish the probability of large wildfires.

1960 to the Present—Integrated pest management (IPM) is now the method used to protect forests from insect outbreaks. With IPM,

... all aspects of a host-pest system are studied and weighed. The information considered in selecting appropriate management strategies includes the impact of the unregulated pest population on various forest values, alternative regulatory tactics and strategies, and benefit/cost estimates of these alternative strategies. Regulatory strategies are based on sound silvicultural practices and the ecology of hosts and pests, and consist of a combination of tactics such as timber stand improvement plus selective use of pesticides. An underlying principal in the choice of a strategy is that it be ecologically compatible or acceptable (36 CFR 219.3).

Mountain pine beetle outbreaks in the Blue Mountains in 1964 and mid-1970s were treated with the fell-pile-burn method. More recent outbreaks in north-central Oregon in the mid-1980s and in south-central Oregon and north-central Washington in the late 1980s, and early 1990s have destroyed lodgepole and young ponderosa pines (USDA Forest Service 1938-91). Some salvage logging has occurred, but the primary treatment has been to thin hazardous stands to increase tree vigor and resistance to insect attack.

Western pine beetle outbreak areas increased from 106,000 acres in 1959 to 392,000 acres in 1962, with most outbreaks in Oregon. Some sanitation/salvage treatments were used for outbreaks occurring in 1974 and 1988 to 1990 (Smith 1990). Mortality has recently occurred in second-growth ponderosa pine as well as older trees, and is generally attributed to drought stress and overcrowding.

Douglas-fir bark beetle outbreak increases were found in the Blue Mountains and in northeast and north-central Washington in 1963. Populations also significantly increased in the Blue Mountains between 1988 and 1990, with beetles attacking trees already stressed by western spruce budworm defoliation and persistent drought. The primary treatment has been salvage logging (USDA Forest Service 1938-91).

Since 1960, three projects were conducted to suppress outbreaks of the tussock moth in eastern Oregon and Washington (fig. 15). In 1964 and 1965, more than 150,000 acres were treated in central Oregon using aerial applications of DDT. Those populations collapsed partly as a result of spraying and partly because of a virus epizootic (Perkins and Dolph 1967). Four chemicals were tested on the tussock moth in 1973: bioethanomethrin, carbaryl, mexacarbate, and trichlorfon. In 1973, the tussock moth infested 689,760 acres in eastern Oregon and Washington and killed 17,270 acres of trees (Pettinger and Johnson 1974). In Washington in 1974, about 91,000 acres were treated with DDT, after special permission was obtained from the Environmental Protection Agency to use the pesticide (Graham and others 1975). In 1991, an apparent increase in tussock moth populations detected by a pheromone-based early warning system installed about 12 years before (Willhite 1993) prompted officials to treat 116,344 acres with *Bacillus thuringiensis* (B.t.)—a biological control agent. Tussock moth populations were reduced, but this may have been because of natural causes.

DDT was still used to suppress outbreaks of western spruce budworm in the early 1960s. In 1976, about 305,000 acres were treated using malathion ultra-low volume. An additional 7700 acres were treated with carbaryl. Carbaryl was used on about 325,000 acres in eastern Oregon and Washington in 1979 and again on 170,000 acres in 1982. Since 1987, B.t. was used in south-central Washington and central Oregon.

Forest diseases are generally combated by favoring resistant stand structures and resistant or tolerant species in thinnings and plantings—generally ponderosa pine, western larch, western white pine, and lodgepole pine. Stump removal to minimize inoculum of *Armillaria* root disease has been attempted in a wide range of settings, but has usually been found to be more expensive than other alternatives. Forest diseases, especially dwarf mistletoes, account for substantial growth and mortality losses, but because mortality each year from mistletoe is not spectacular, mistletoe infestations are often ignored. Still, mistletoes as a group are responsible for greater growth reduction and mortality losses to timber production than any other insect or disease. Dwarf mistletoes are readily treated by using conventional silvicultural techniques. Mistletoe suppression projects such as removal of inoculated trees, have been funded by the National Forests both in coordination with timber harvesting and at separate times.

Many forests in eastern Oregon and Washington are now susceptible to, or presently under attack by various insects and diseases (Hessburg and others 1993, Lehmkuhl and others 1993), exacerbating the current high fire risks. Some stands can be made more vigorous and less susceptible to insects, diseases, and fires by using well-planned silvicultural operations, such as thinnings or regeneration harvests. Some stands are already too weak to benefit from treatment as for the others, methods have been developed that can aid in determining if the stands that can be invigorated. Furthermore, silvicultural operations that can strategically pattern landscapes to avoid the worst catastrophes. These operations include thinning some stands by timber removal or controlled ground fires, regenerating some stands to a more robust condition using controlled hot fires or regeneration harvest methods, maintaining some stands with high relative density to create shaded fuel breaks that will slow or stop ground fires. These operations may not be economically justified on the basis of timber revenues alone, but money received from thinning and harvesting these stands can help defray the costs.

Riparian Management

Pre-1930—The public grew concerned about the effects of grazing on siltation of irrigation reservoirs and watersheds. Deforestation associated with grazing promoted flooding, causing even more concern. Managing forests for flood control was one of the founding principles of National Forests (Steen 1976). Floods were controlled by regulating grazing, harvesting, and, in conjunction with irrigation, damming streams.

The first irrigation systems in eastern Oregon and Washington were developed by early missionaries, and by private individuals or companies. Irrigation increased rapidly in the early 1900s after the creation of irrigation districts that cooperated with the government (Perala and Collins 1990). Fish ladders were installed in some streams as early as 1915 when some people voiced concern about the salmon that were unable to return to spawning areas (Wissmar and others 1993).

Farmers in the Blue Mountains, central Oregon, and south-central Washington were among the first in the region to irrigate, a practice that spread to other areas (fig. 16). For example, in 1902, an estimated 250,000 acres were irrigated in eastern Washington. By 1938, 5 million acres were under irrigation in the Columbia basin (Pacific Northwest Regional Planning Commission 1938; Resner 1938). Between 1900 and 1920, dams were built in the subsampled area of the Yakima River basin (tables 3A, 3B), the only dams built in this area. One effect of the dams was to hinder fish migration. To prevent siltation of the irrigation reservoir, grazing and harvesting were regulated, and stream channels were straightened to prevent streambank erosion. This straightening appears to have adversely affected riparian and stream habitats by dewatering, streambed scouring, and reduction of silt below desirable amounts for fish breeding (Wissmar and others 1993).

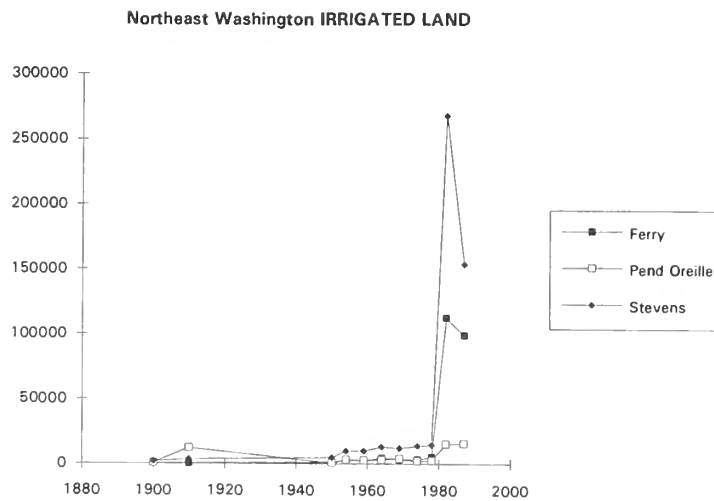
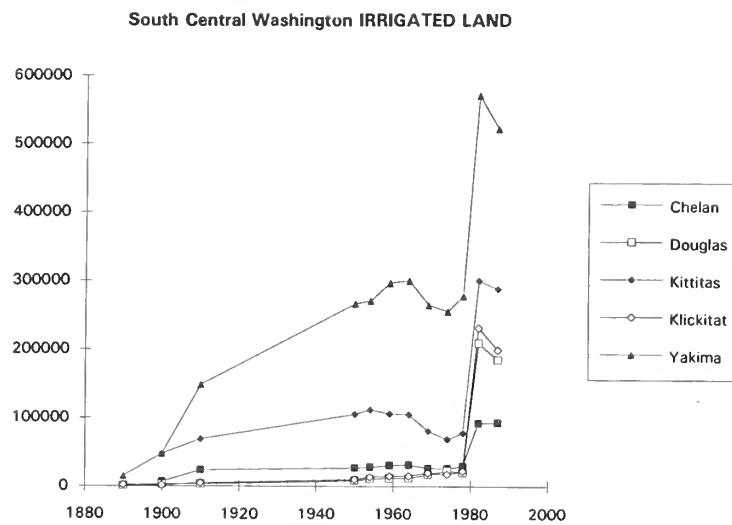
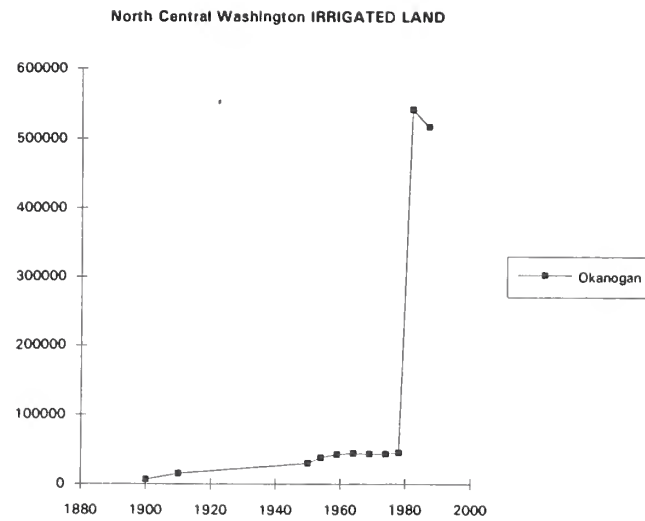
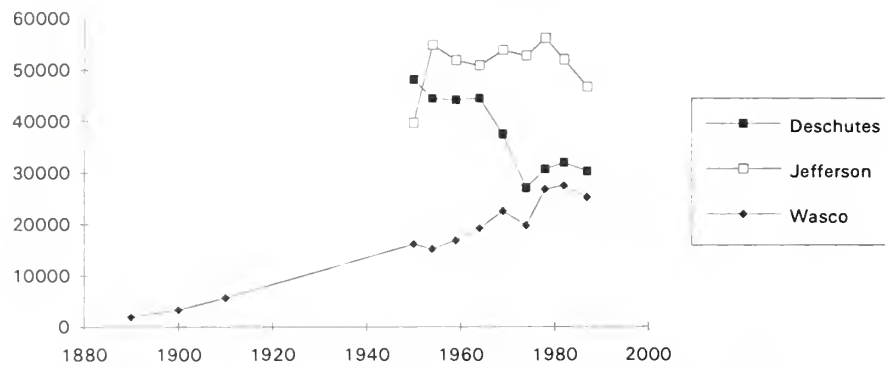
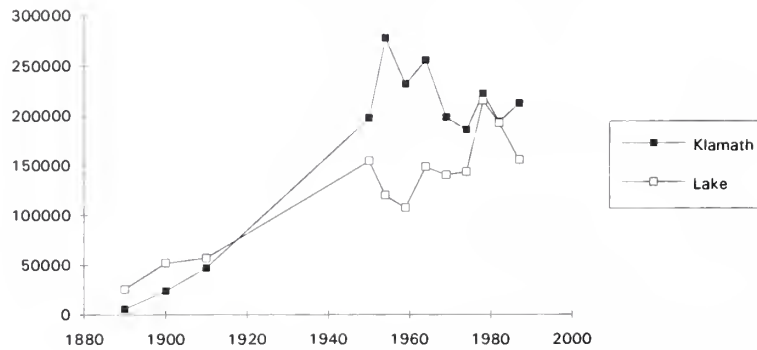


Figure 16. Irrigation occurred early in places such as the Blue Mountains, central Oregon (16B), and south-central Washington (16A) (U.S.Bureau of the Census). Irrigation was not extensive until much later in other places. Early irrigation involved damming of rivers and streams; later irrigation also used well water.

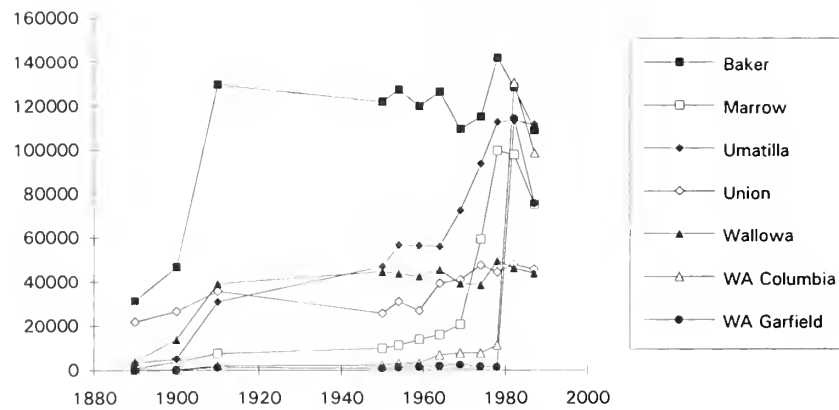
North Central Oregon IRRIGATED LAND



South Central Oregon IRRIGATED LAND



Blue Mountains IRRIGATED LAND



Central Oregon IRRIGATED LAND

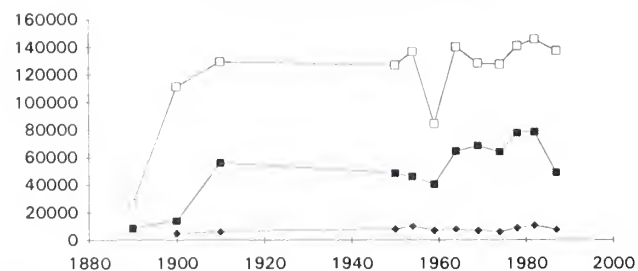


Figure 16 (continued)

Just as managers had no concept of an ecosystem, at the time no concept defined “riparian zones” as specific entities to manage or safeguard. Consequently, managers addressed specific issues; they did not try to protect the basic patterns and processes of riparian habitats or streams. For example, streams were not protected from sheep and cattle, animals that often removed vegetation from the stream banks, trampled the wet soil, caved in the stream banks, and created wide, shallow streams with little shade or pools for fish.

1930 to 1960—Flood control efforts continued with the channeling of streams, which coupled with grazing and road building, worked to reduce riparian habitats. Fish habitats were degraded through scouring of fine sediments. Irrigation efforts increased in many areas (tables 3A, 3B; fig. 16); however, the ecological and social costs of flood control and irrigation did not go unnoticed, and some people called for action to remedy the problems. For example, fish ladders were installed at dam sites (Perala and Collins 1990). The importance of riparian zones was still not understood, and these habitats continued to decline as a result of dewatering, straightening of channels, and fragmentation by roading.

1960 to the Present—Riparian zones are now recognized as habitats highly interconnected with streams; consequently, the practice of leaving streamside buffers strips of undisturbed or less disturbed vegetation began. Relatively little is known about riparian zone management. Evidence suggests that the quantity and quality of riparian and stream habitats for aquatic and amphibious species are reduced by such practices as channeling rivers and streams, eliminating access to side channels, damming, removing woody debris, and preventing the flow of sediment down the channel. Erosion, mass wasting, and siltation cannot be prevented, but they can be brought within ranges which do not eliminate other ecosystem values. Preventing small siltation events may simply create conditions for larger events in the future, in the same way that preventing small fires leads to fuel buildup and the increased likelihood of large fires. Some sand, silt, and gravel in the stream channel is necessary for many aquatic species, and some thrive after large siltation events. Others require habitats that have not been disturbed for a long time.

Little is known about riparian and aquatic species and their habitat needs. Current management practices attempt to prevent or avoid most disturbances in riparian zones. More research will be needed to determine appropriate types, timing, and rates of disturbances for maintaining stream and riparian biodiversity.

Besides direct stream manipulation, forestry-related activities that contribute most to stream siltation are poor road and bridge construction and maintenance, and poor grazing practices (Seaton and others 1973). Many old roads and bridges were improperly constructed, and need extensive reconstruction to maintain their usefulness and to mitigate their adverse effects on streams.

Wildlife Management

Pre-1930—Early wildlife management programs emphasized both protection and enhancement. For example, sheep and cattle were protected against natural predators such as wolves and grizzly bears (Steen 1976). Game species were managed to produce a harvestable surplus. Numerous species were introduced or reintroduced, and populations were protected against overharvesting. Severe restrictions were placed on the harvest of mule deer and elk on the eastside in the early 1900s to allow populations to rebuild. Elk were transplanted from Yellowstone National Park and Jackson Hole, Wyoming, between 1912 and 1931 to supplement small local herds (Couch 1953, Robbins and others 1982). Control of some native predators has made these predators locally extinct or endangered. Game management has increased some elk populations well above those encountered by early settlers.

1930 to 1960—With increased deer and elk herd sizes, more active game management occurred (discussed earlier), along with fish management (Perala and Collins 1990). At times, elk were transplanted to areas where they previously had been scarce. For the most part, however, wildlife management was restricted to animals hunted for sport and fishing.

1960 to the Present—Recent concerns for wildlife have extended beyond protecting game species and controlling predators, to include efforts aimed at protecting and conserving all species. The Endangered Species Act attempts to protect all species, yet protection measures are generally initiated only after species are already in serious trouble. A conflict that may soon emerge in eastern Oregon and Washington involves threatened or endangered species that have conflicting requirements. Historically, stand structures were maintained in a dynamic state across landscapes through natural growth and disturbance regimes. Thomas and others (1979) were among the first to suggest an integration of non-game wildlife species in managed forests. Recent studies have shown a strong association between many non-game wildlife species and late successional forests. People often react to species in danger by wanting to curtail all management activities—with little incentives or funds available for active or preventive management.

Wilderness Areas

Pre-1930—The *Forest Service Use Book* of 1905 specified that the “prime object of the forest resources is use” (Steen 1976). A change of philosophy is reflected in 1924, when the first USDA Forest Service wilderness area was designated (Steen 1976) (not in Oregon or Washington).

1930 to 1960—No wilderness areas were established in eastern Oregon and Washington during this period; however, parts of National Forests in eastern Oregon and Washington became National Parks.

1960 to the Present—Other amenity and aesthetic values are encouraged and required by society on National Forest lands. Both recreational use and wilderness have increased substantially on National Forests (figs. 17, 5), although most types of recreational (fig. 17) use are not suitable to wilderness areas. Fires have been excluded from both wilderness and nonwilderness areas, and fire hazard in wilderness mirrors that of nonwilderness. In fact, wilderness areas may have higher hazards than nonwilderness because wilderness areas were commonly designated in high-elevation vegetation types that still retained their pristine qualities, and lacked prior harvest entry. These high-elevation types more often than not have high fire-severity regimes.

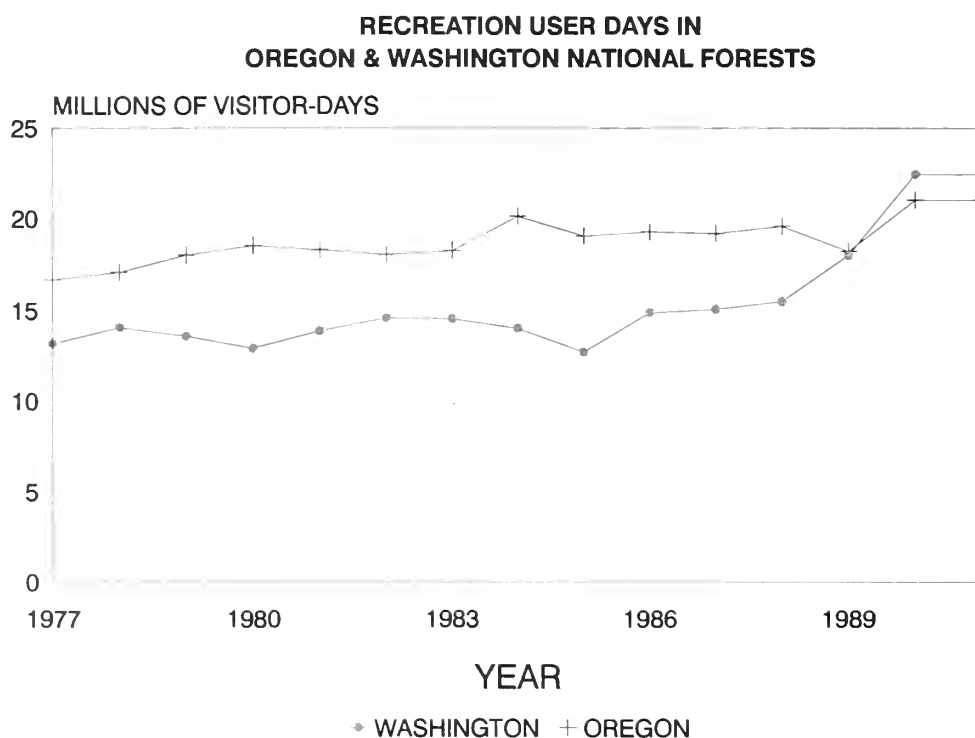


Figure 17A. Recreation visitor-days on all National Forests in Oregon and Washington (eastern and western). Recreation use of National Forests has greatly increased in Washington since 1985 (USDA Forest Service 1975-91).

Silviculture Practices

Pre-1930—Silvicultural operations, such as active regeneration and stand tending, were generally absent in the late 1800s and 1900s; timber was simply extracted. Harvesting patterns were sometimes adjusted to promote regeneration through partial cutting and seed-tree harvesting. By the 1920s silvicultural practices were still not very intensive in eastern Oregon and Washington. In 1923, trees were planted on only 1615 acres in National Forests in Oregon and Washington—none were planted in eastern Oregon or Washington (USDA Forest Service 1923, 1952-62).

1930 to 1960—Funding for silvicultural activities was provided through a revolving fund from timber receipts by the Knudtson-Vandenberg Act of 1930 in an effort to ensure that silvicultural activities were continued to provide future timber supplies. By tying silvicultural activities to timber production, silvicultural activities to enhance other values but not justifiable on the basis of timber production were not done.

Silvicultural practices for timber production increased dramatically during this period, with a variety of planting, seeding, thinning, and pruning practices successfully attempted (fig. 18). Planting and thinning efforts during the 1950s and 1960s, however, were closely spaced, and many stands treated during that period are still overcrowded—a common problem throughout the United States (Oliver 1986). In the mid-1950s, pruning was the preferred method of stand improvement in eastern Oregon and Washington, and was done during seasons when other operations were not feasible. The increasing wages, increasing mechanization of other operations, and concomitant movement of people to urban areas in the 1950s reduced the forest labor force and increased costs, thus making pruning uneconomical.

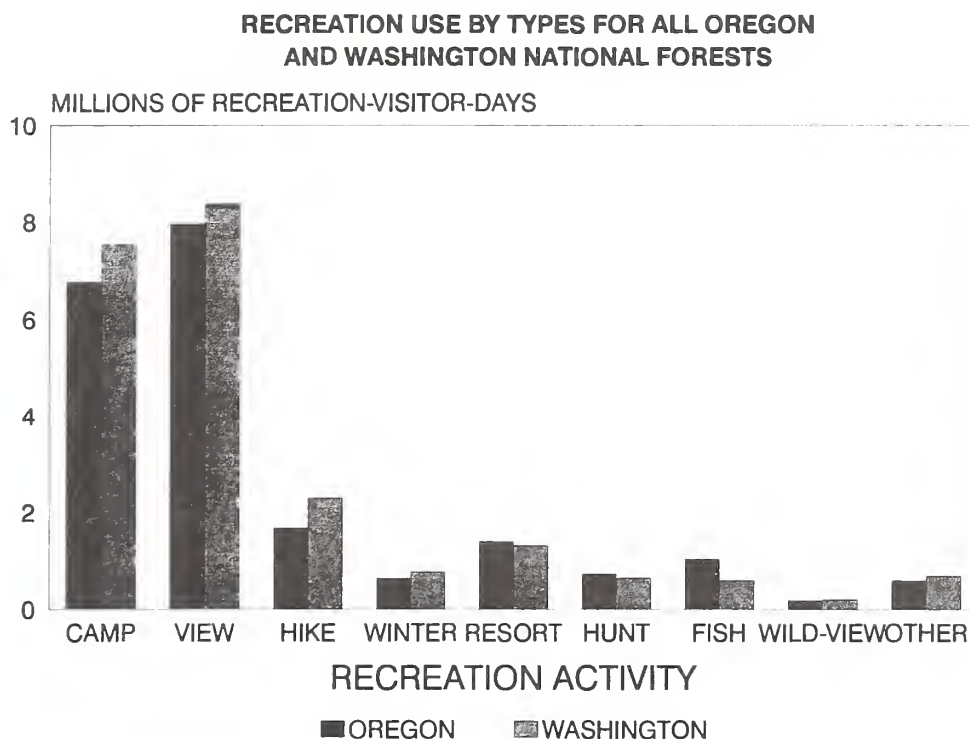


Figure 17B. Recreation use in Washington and Oregon by activity (both eastern and western parts; more specific data were not available) in 1991. Most recreational activity is viewing (near automobile) and camping, picnicking, and swimming (USDA Forest Service 1975-91):

Camp = camping, picnicking, and swimming
 View = mechanized travel and viewing scenery
 Hike = hiking, horseback riding, and water travel
 Winter = winter sports
 Resorts = resorts, cabins, and organization camps

Hunt = hunting
 Fish = fishing
 Wild-view = nonconsumptive fish and wildlife use
 Other = other recreational activities

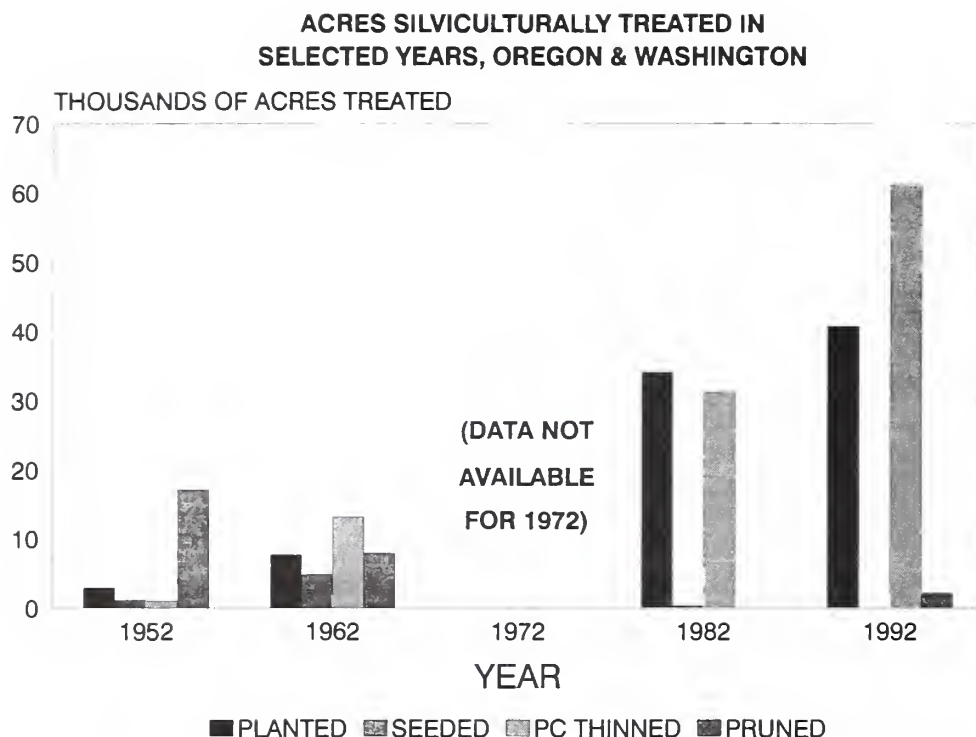


Figure 18. Silvicultural activities have generally increased dramatically in eastern Oregon and Washington since 1950. Planting and precommercial thinning have increased, and pruning has declined (USDA Forest Service 1923 and 1952-62; USDA Forest Service 1975-1991).

Increased silvicultural activities from 1930 to 1960 were primarily experimental in nature, but infrastructure and experience was developing to allow more intensive and extensive silvicultural activities in the coming decades.

1960 to the Present—Most silvicultural activities to date are funded from timber sale receipts under the Knudtson-Vandenberg Act of 1930. These receipts were made available to fund other resource management objectives with the National Forest Management Act. Presently, the Silviculture section in Forest Service organizations is a subset of the Timber Management division. Historically, silvicultural treatments were primarily considered where they yielded a financially acceptable economic return; this consideration is changing.

Eastern Oregon and Washington contain many overcrowded stands that should be thinned to prevent increasing susceptibility to insects, diseases, and fires and to create a greater diversity of plant and animal habitats. Many of these stands have not been reported as silviculturally in need of thinning by local National Forest managers; consequently, funding has not been considered by higher-level managers for treating these stands. Reasons for not reporting these stands are unclear.

Specific silvicultural operations and the extent of their application: early spacing (precommercial thinning)—one of the greatest problems in the forests of eastern Washington and Oregon is the large area of stands of overly crowded, small-diameter trees. These stands should be thinned before the trees grow tall, to allow remaining trees to grow large in diameter to avoid insect and disease attacks, and to avoid snow breakage by improved height-to-diameter ratios.

The area reported as needing and receiving thinning in eastern Oregon and Washington from 1976 to 1991 is shown in figure 19. Many more stands are overcrowded and will decline in vigor if not thinned, but were not reported. Thinning will reduce fire danger in the long run, increase habitat diversity, and

produce jobs. Thinning has historically been justified for economical production of timber. This economic consideration gives lowest priority to poor (in growth potential), dry sites, and so these sites are often not thinned (fig. 20). Poor sites are often droughty and prone to insect attacks and fires--especially if not thinned. These poorer sites, created by catastrophic fires many decades ago, contain the largest areas of overcrowded stands on the eastside.

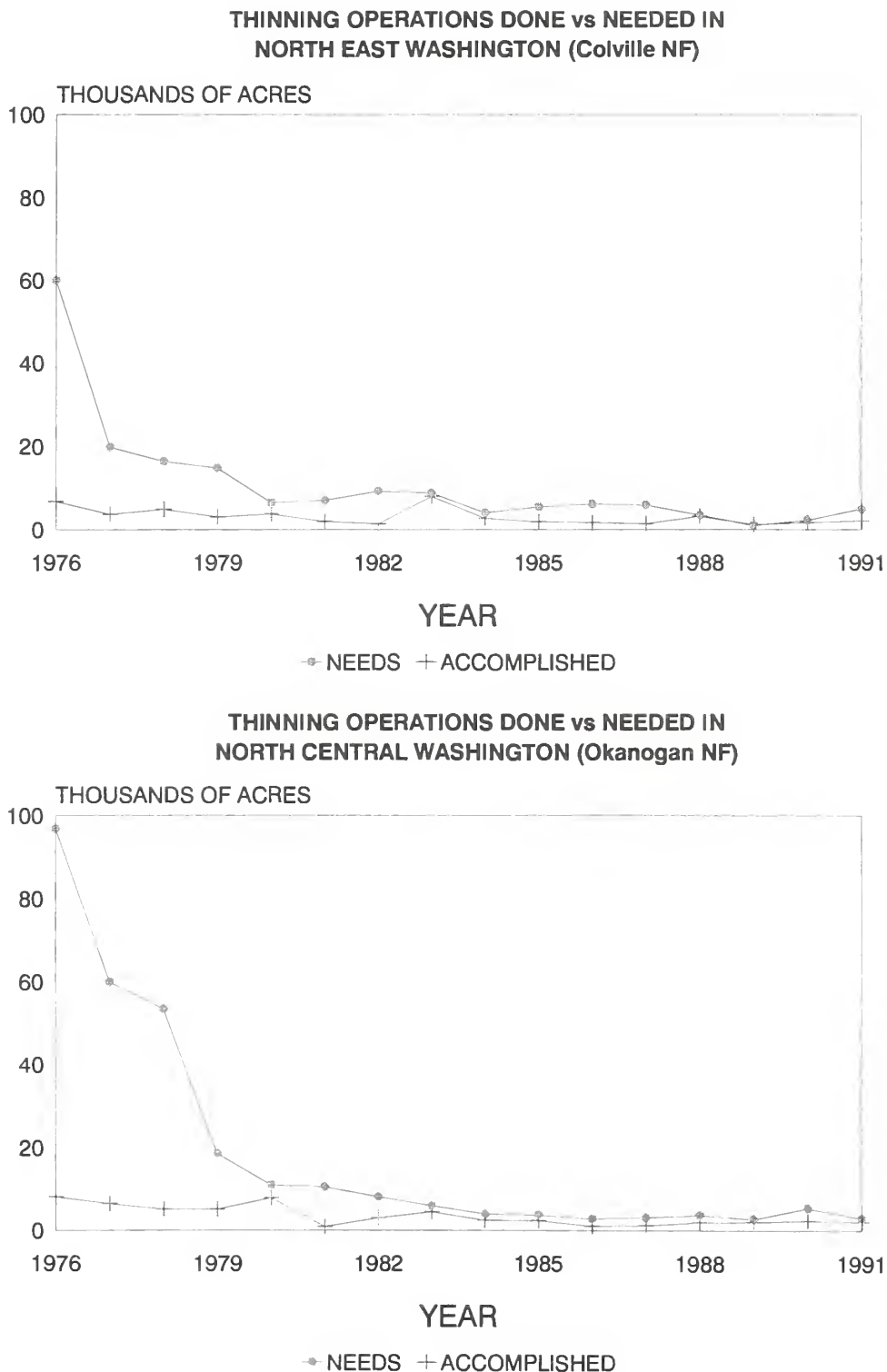
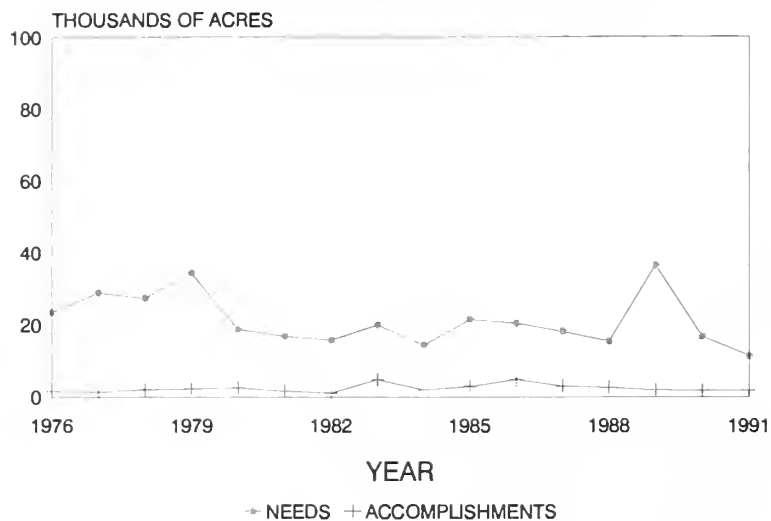
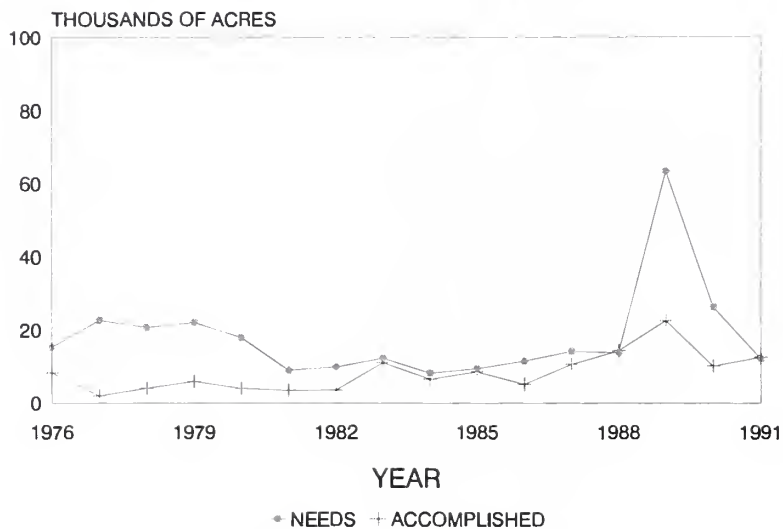


Figure 19. Thinning operations needed and accomplished by subregion and year in eastern Washington (19A) and Oregon (19B) (data on file, Regional Silviculture Office, USDA Forest Service, Portland, Oregon).

**THINNING OPERATIONS DONE vs NEEDED IN
SOUTH CENTRAL WASHINGTON (Wenatchee NF)**



**THINNING OPERATIONS DONE vs NEEDED IN
NORTH CENTRAL OREGON (Deschutes NF)**



**THINNING OPERATIONS DONE vs NEEDED
IN BLUE MTNS (Umatilla/Wai-Whit NF)**

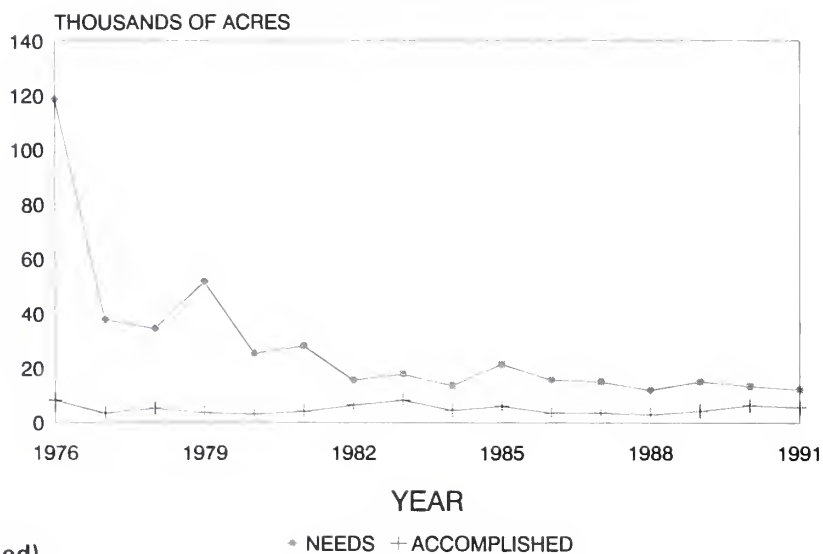
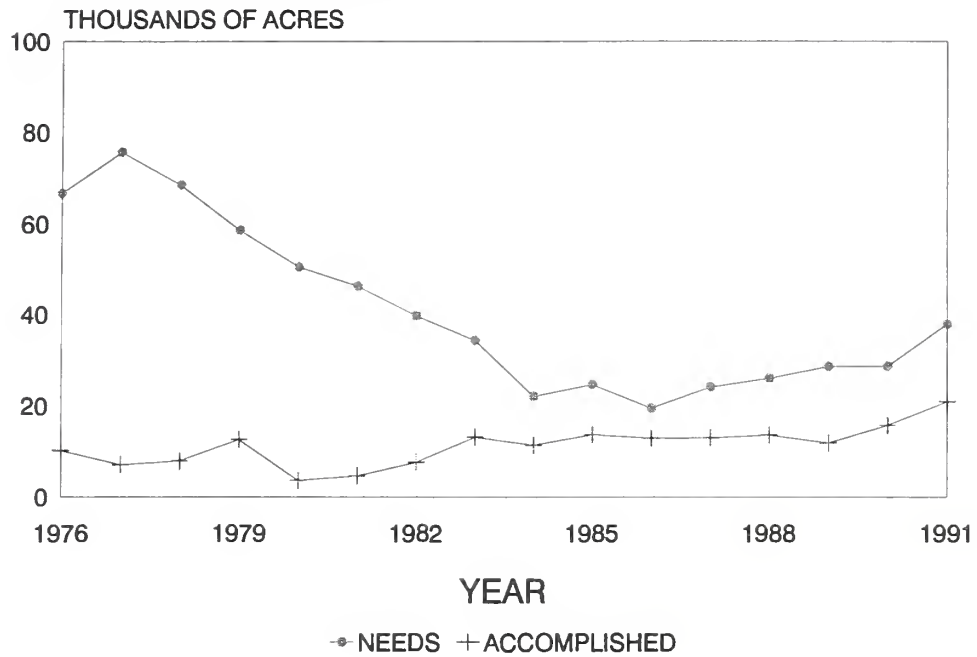


Figure 19 (continued)

**THINNING OPERATIONS DONE vs NEEDED IN
SOUTH CENTRAL OREGON (Fremont/Winema NF)**



**THINNING OPERATIONS DONE vs NEEDED
IN CENTRAL OREGON (Malheur/Ochoco NF)**

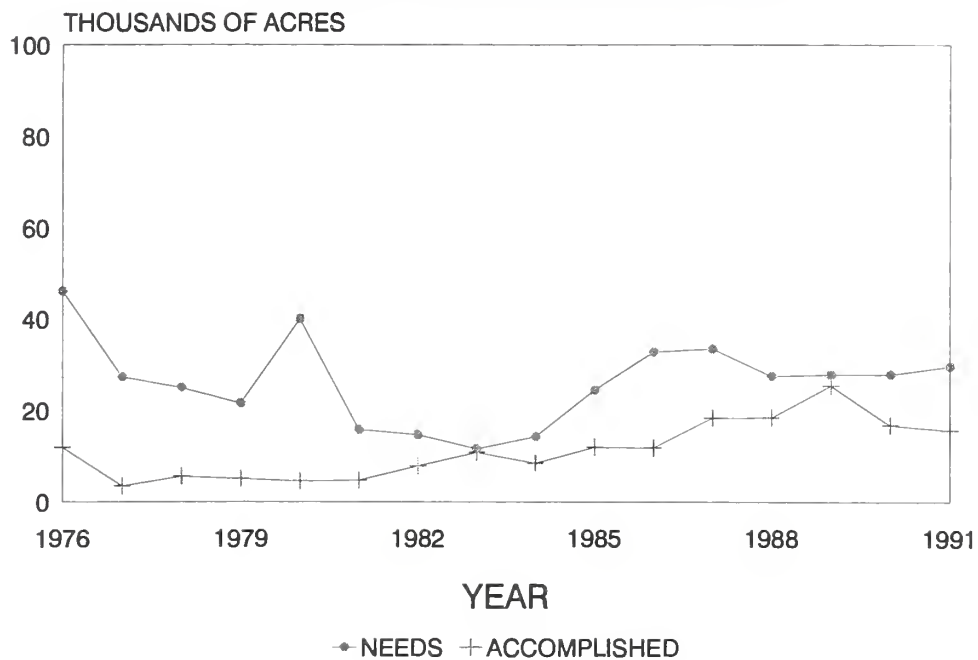


Figure 19 (continued)

Some stands are thinned with a reasonable financial return on investment by removing small-diameter, merchantable, understory trees and allowing the larger, vigorous overstory trees more growing space. Stands of two or more canopy layers are often thinned (overstory removal) with a financial return to the landowner from the overstory trees—usually with varied success in stimulating the understory to grow. This practice may be of questionable value, however, if overstories consist of seral species resistant to disease and insects and understories are species more susceptible to insects and diseases. Overstory removal would amount to a high-grading of resistant species, leaving residual stands that are susceptible to root diseases, defoliators, stem decays, and some bark beetles and dwarf mistletoes.

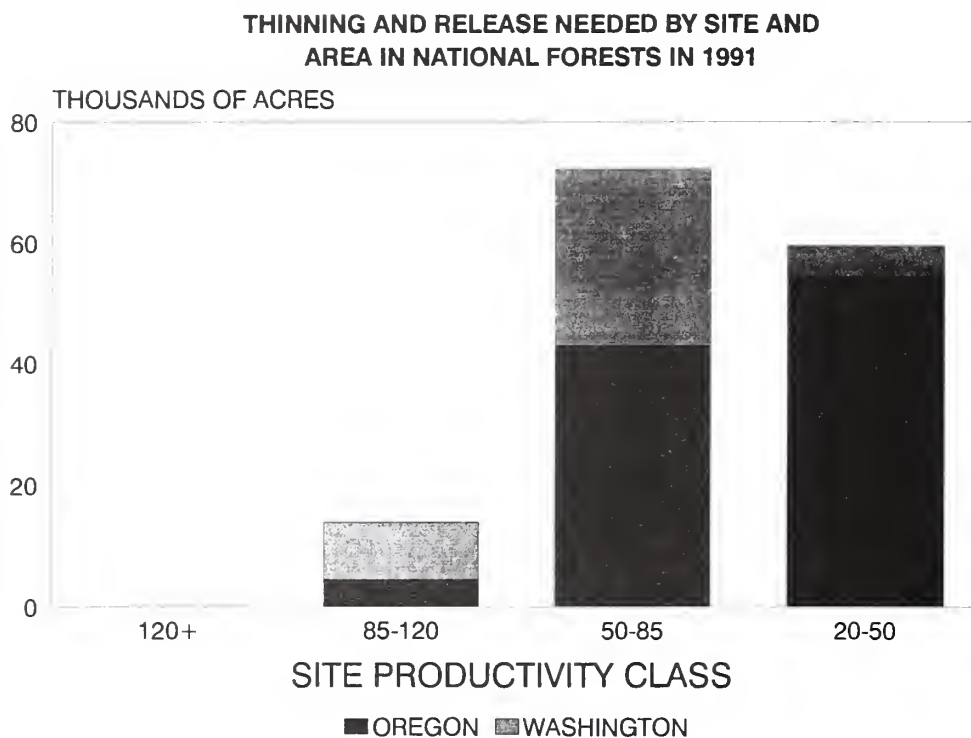


Figure 20. Most thinning and release needs are listed on poor sites. If these stands are not thinned, they become susceptible to insects and fires (USDA Forest Service 1975-91; data from 1991 report).

Weed control—weed control operations are generally done on fewer acres than thinning (fig. 21), and on only a portion of the total area needed each year. The purpose is not necessarily to kill competing plants, but to hinder them long enough to allow trees to outgrow them. Under ecosystem management, weed control may not be desirable in all stands. Shrubs mixed with trees, for example, can provide for habitat diversity or nitrogen-fixation. Weed control by sheep and cattle grazing has been suggested and tried but is not commonly practiced.

Regeneration—Where both even-aged and uneven-aged management are practiced in National Forests in eastern Oregon and Washington, many areas are artificially regenerated by planting seedlings to ensure an adequate mixture of tree species (fig. 22). Lodgepole pine and true firs regenerate well naturally. Nearly all areas in eastern Oregon and Washington that are harvested are regenerated within five years. Sometimes regeneration fails (fig. 22) because of certain critical site variables. Further harvest is often stopped on National Forests in areas where regeneration is found not to be successful.

In artificial regeneration a variety of seedlings sizes and hand planting equipment is used. Most trees planted are Douglas-fir and ponderosa pine, although genetically improved western white pine, western larch, lodgepole pine, and other species are also used.

Fertilization—Fertilization of forest lands is possible, but only recently has been done in eastern Oregon and Washington and only to a limited extent. Of the 4647 acres in eastern Oregon and Washington listed in 1991 as needing to be fertilized (justifying the need based on economic return to timber production), only 2058 acres were fertilized. Fewer acres were fertilized in 1990.

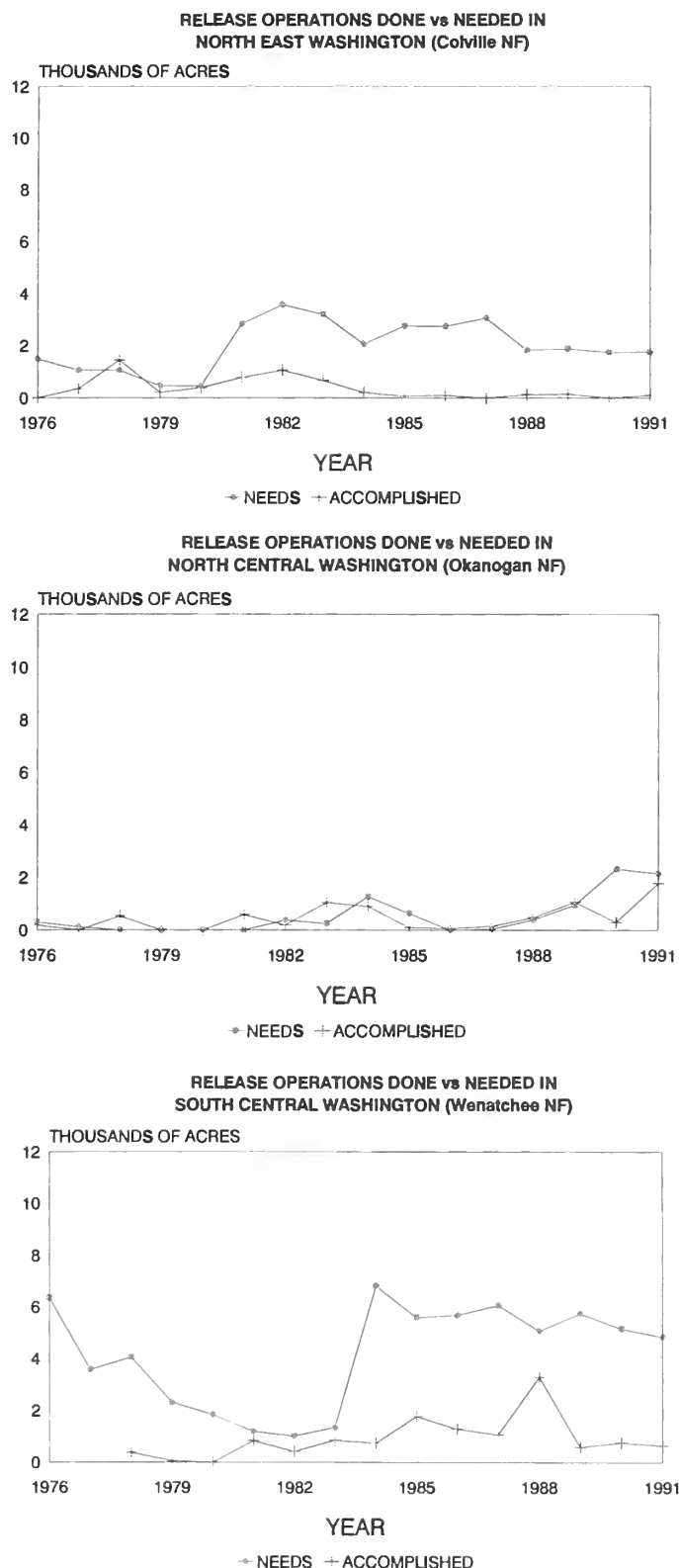


Figure 21. Release operations needed and accomplished by subregion and year in eastern Washington (21A) and Oregon (21B) (data on file, Regional Silviculture Office, USDA Forest Service, Portland, Oregon).

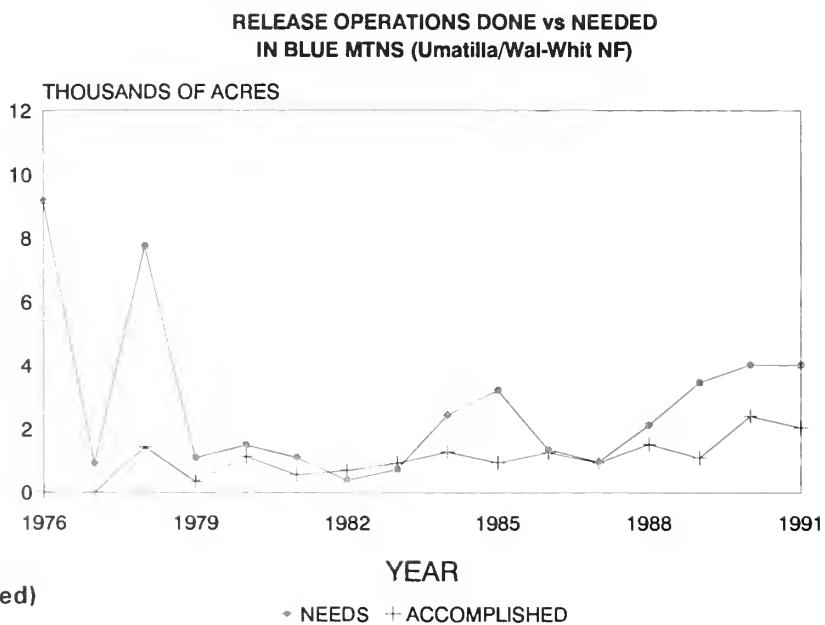
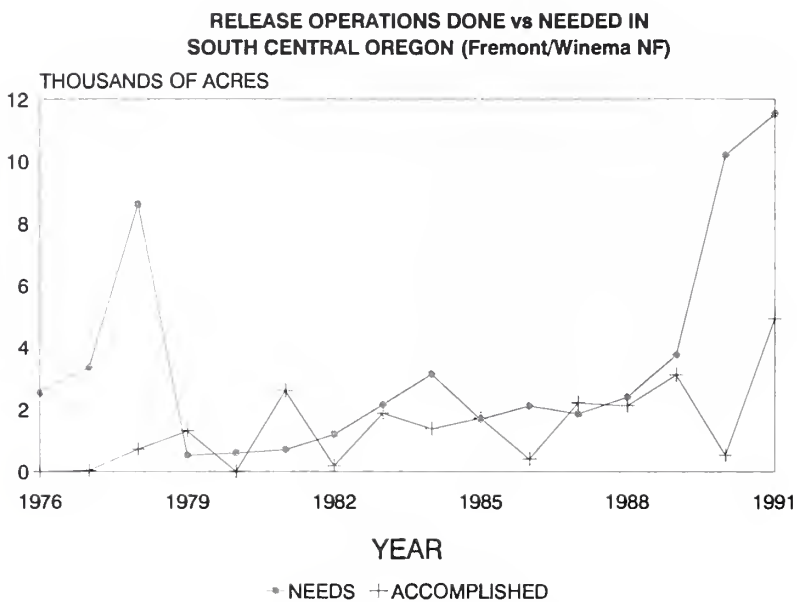
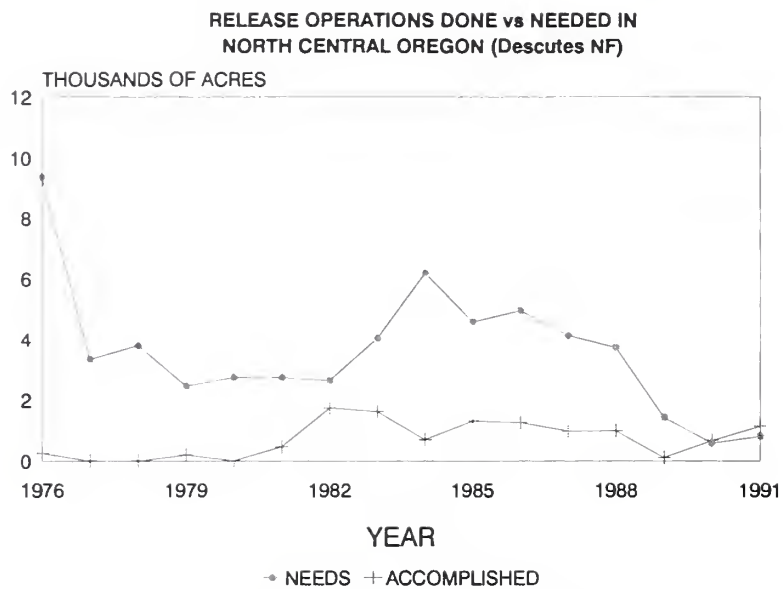


Figure 21 (continued)

**RELEASE OPERATIONS DONE vs NEEDED IN
CENTRAL OREGON (Malheur/Ochoco NF)**

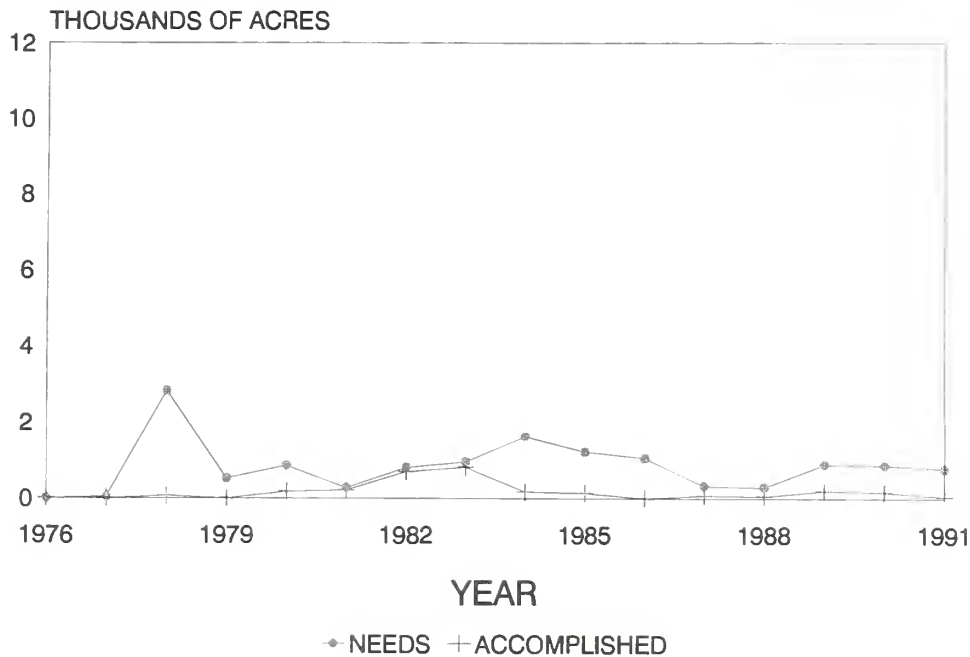


Figure 21 (continued)

**REGENERATION OP'S DONE vs NEEDED IN
NORTH EAST WASHINGTON (Colville NF)**

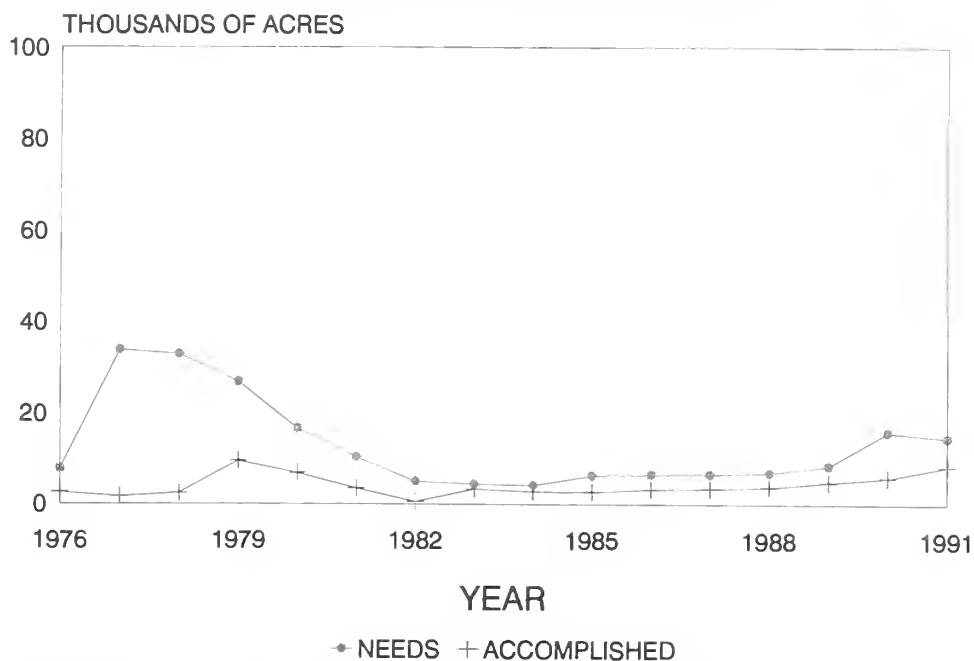
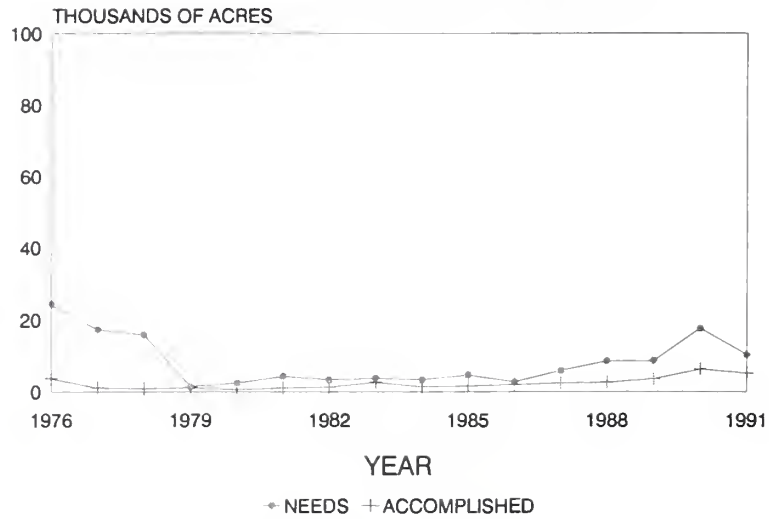
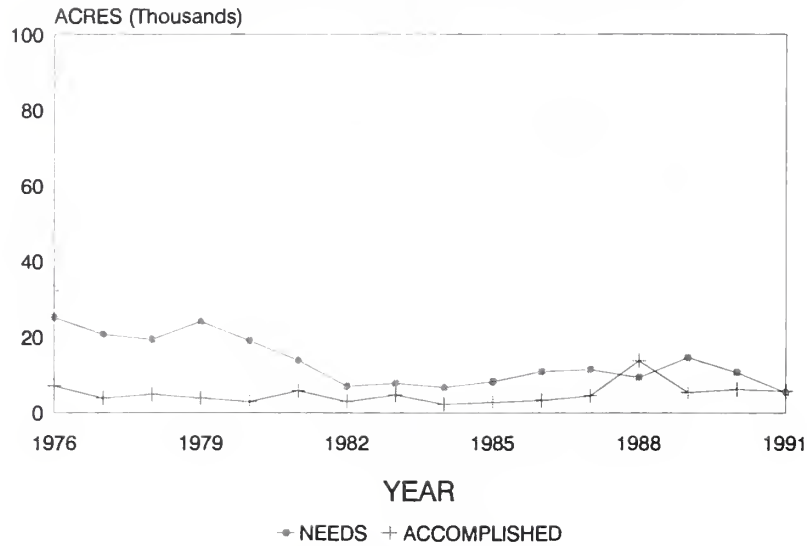


Figure 22. Regeneration operations needed and accomplished by subregion and year in eastern Washington (22A) and Oregon (22B) (data on file, Regional Silviculture Office, USDA Forest Service, Portland, Oregon).

**REGENERATION OP'S DONE vs NEEDED IN
NORTH CENTRAL WASHINGTON (Okanogan NF)**



**REGENERATION OP'S DONE vs NEEDED IN
SOUTH CENTRAL WASHINGTON (Wenatchee NF)**



**REGENERATION OP'S DONE vs NEEDED IN
CENTRAL OREGON (Malheur/Ochoco NF)**

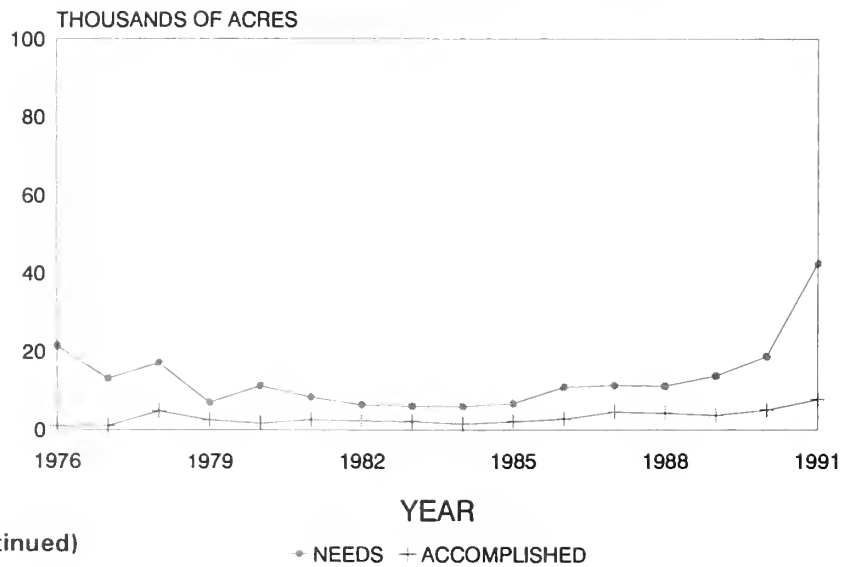
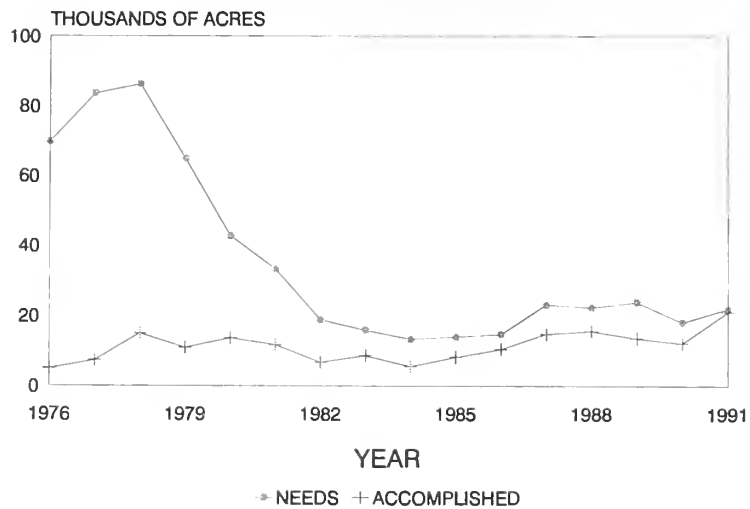
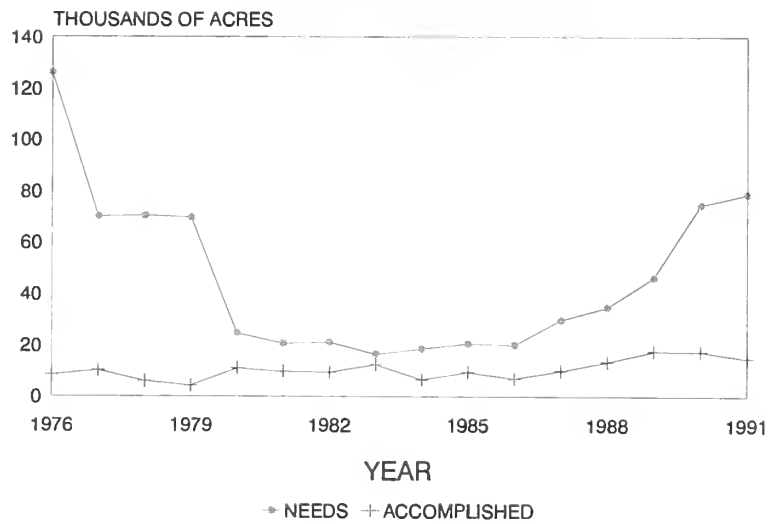


Figure 22 (continued)

**REGENERATION OP'S DONE vs NEEDED IN
SOUTH CENTRAL OREGON (Fremont/Winema NF)**



**REGENERATION OP'S DONE vs NEEDED IN
BLUE MTNS (Umatilla/Wai-Whit NF)**



**REGENERATION OP'S DONE vs NEEDED IN
NORTH CENTRAL OREGON (Deschutes NF)**

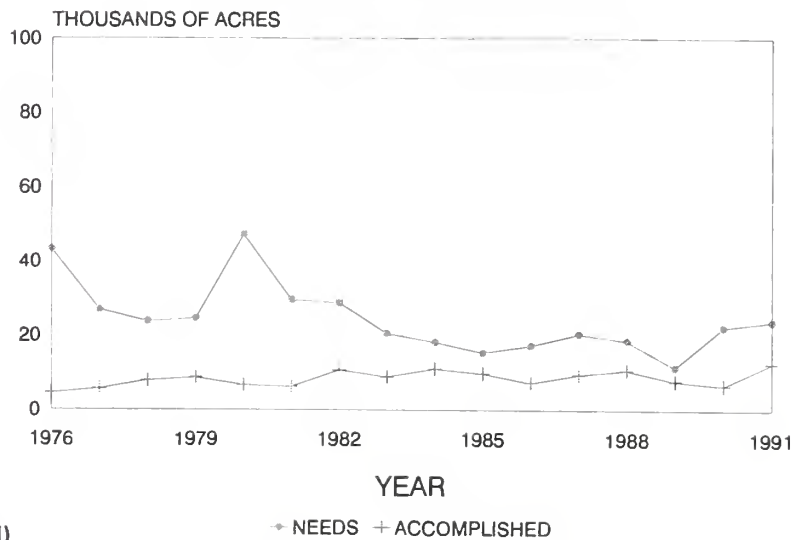


Figure 22 (continued)

Tree improvement—The Forest Service currently has an extensive genetic resource program in eastern Oregon and Washington with the goals of providing leadership in genetic conservation and resource management, integrating genetic principles into management, maintaining tree-improvement programs, educating and transferring technology, and improving cooperative efforts.

For 15 tree species, 32,334 parent trees are included in the Tree Improvement Program. In addition, seed orchards presently cover 549 acres in eastern Oregon and Washington. These orchards are for seven tree species with a total of 6284 families—ponderosa pine, Douglas-fir, western white pine, sugar pine, lodgepole pine, Engelmann spruce, and western larch. Even planted seedlings not taken from selected trees are taken from known, local seed sources. In the future, all species should be screened for resistance or tolerance to insects, diseases, and sensitivity to environmental stresses to broaden the adaptability of the genetic resources.

Pruning—Pruning was done in eastern Oregon and Washington in the early 1950s. Pruning is once again being recognized as a useful silvicultural activity (Fight and others 1992). In 1989, two National Forests in eastern Washington and Oregon reported 1937 acres in need of pruning, yet no pruning was done. By 1991, 11,090 acres were listed as needing pruning, but very few acres were actually pruned. Pruning is generally done with hand and pole saws. Various mechanized pruning machines have been tried but none are used operationally. Pruning, in combination with thinning to remove suppressed trees, may be a useful technique to enhance the value of young, dense stands for northern spotted owls. These techniques could be especially effective if used in combination with prescriptions for snags and woody debris.

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APPENDIX A

Information Sources

Information for this history came from a variety of sources and covered different geographic units. U.S. census data were collected for various counties and so included nonforested and forested areas. USDA Forest Service Resource Reports included all forest lands, regardless of ownership. USDA Forest Service Annual Reports and unpublished data (available courtesy of the USDA Forest Service Regional Office, Portland, and elsewhere) covered primarily activities on National Forest Land. USDA Forest Service fire suppression data and similar pest-control information included both National Forests and other forest land within the fire or pest control area. Some information on non-Federal forest lands was taken from unpublished data (CINTRAFOR 1993).

Systematic sources of data described above were more available for recent decades; early management information was taken from a variety of direct and indirect sources. Various scientific and technical publications (books, journals, and reports) describing management practices were used to supplement more specific information.

In addition, two drainage basins were subsampled in depth for very area-specific information (fig. 1). These basins were the Yakima River basin in south-central Washington and the Grande Ronde River basin in the Blue Mountain area. Fifteen (Yakima) and twenty (Grande Ronde) selected watersheds within these basins were chosen, with watershed size varying from about 15,00 to 30,000 thousand acres. Detailed history of various, selected practices were reconstructed from past records wherever possible (tables 3A, 3B; figs. 5, 12; the authors are grateful to Donald Spurbeck, Bonnie Java-Sharpe, Elizabeth Goulet, and John Beebe for the Yakima basin information and to Todd Welter, Ken Williamson, and Charles Ernst for the Grande Ronde information). Some data were unavailable for all watersheds; therefore, the information for each area was adjusted to reflect the extent of practices per million acres of forest land. Specific information was provided by experts in the following areas: fire management, Erik C. Christiansen; bark beetle management, Iral Ragenovich; defoliating insect management, Dave Wallez Bruce Hostetler; genetic resource program, Sheila Martinson; silvicultural activities, Ernie Meisenheimer and Don Connett. All are with the USDA Forest Service. The authors are also grateful to Dr. Stephen J. Pyne of Arizona State University for his review and editing of the fire section of this paper.

Consistencies among management trends from census data, Forest Service Resource Reports, Forest Service annual reports, fire and pest-management information, various technical and scientific journals, and sampled data from the selected drainage basins suggest that the trends reported in this paper are relatively accurate.

APPENDIX B

Timber Harvest Practices

Timber has generally been harvested in both even-aged and uneven-aged systems. Even-aged systems include clearcutting, seed-tree cutting, and shelterwood cutting. They mimic stand-replacing disturbances (with occasional trees left in seed-tree and shelterwood stands) because essentially all trees begin after the single harvest disturbance. Clearcutting removes all trees of the pre-disturbance age; seed-tree cutting leaves a few, vigorous trees to provide seeds for regenerating the new stand; shelterwood cutting leaves more overstory trees after the initial harvest to prevent extremes of heat and cold on the regeneration. Residual trees can be removed in seed-tree systems, and are generally removed in shelterwood systems to prevent their shade from reducing growth and vigor of the regenerating stand.

Uneven-aged systems mimic partial disturbances because they leave many living trees within the harvested area but allow regeneration of a new stand. Uneven-aged systems are considered high grading when the most vigorous trees are removed and small, weak (and often scarred and diseased) trees are left, or when the largest, highest value species are removed. Silvicultural selection systems promote vigorous trees of a variety of ages and species by removing weakened trees—as opposed to high grading.

Group selection systems generally leave larger openings than traditional uneven-aged systems and leave a mosaic of stands of many species and structures.

Thinning removes some trees—either from upper canopy layers (high thinning) or lower canopy layers (low thinning). Thinning can be done in conjunction with both even-aged and uneven-aged systems, but with no expectation of obtaining regeneration after a thinning. Much harvesting in eastern Oregon and Washington has been overstory removal, removing scattered, large, older trees in stands in the stem exclusion or understory reinitiation stages after partial disturbances (fig. 4). Technically, overstory removal removes the large, old overstory trees, and so converts the stand to a more even-aged stand. Overstory removal is also technically thinning because it does not create enough disturbance to allow a new age class to regenerate.

Various equipment has been used in harvesting, including horses and oxen, cable systems, railroad systems, rivers (with splash dams), tractors (both track and wheel types), trucks, and helicopters. Often combinations of equipment were used. Horses and oxen were used to drag (yard) logs to a road or stream; they were also used to haul logs to a processing facility.

Cable systems were used to yard logs to a road, often suspending part of the log to reduce ground friction and soil compaction. Rivers were used to move logs to processing plants. Sometimes, logs were accumulated behind a small dam or splash dam; then, the dam was broken and the logs floated downstream on the released water.

Tractors have been used to yard logs. Tractors with treads compact less than tractors with round tires but are slow, and tractors with round tires (rubber-tired skidders) are faster but can compact wet soils of fine texture. Temporary railroads (specially built) have been used to haul wood from yarded areas to processing facilities. Helicopters have been used to yard wood to roads.

Tree branches and limbs are usually left in an area after harvest and can be burned, piled, or piled and burned under controlled conditions to prevent a wildfire. But this practice can prove quite harmful to a site because bulldozers used to pile woody debris disturb the soil, and burning concentrates the nutrients in one place, volatilizes nitrogen, and overheats the soil beneath the slash pile.

Management History of Eastside Ecosystems:
Changes in Fish Habitat Over 50 Years,
1935 to 1992

by

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INTRODUCTION

The recent listing of Snake River spring/summer chinook (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) under the Endangered Species Act has elevated concern over the continued survival of anadromous salmonids in the Columbia River basin. The American Fisheries Society lists 76 native anadromous salmonid stocks in the Columbia River basin that are at a high or moderate risk of extinction (Nehlsen and others 1991, fig. 1). In addition, Oregon Trout lists over 200 stocks that are already extinct in the Columbia River basin (Nehlsen and others 1991). Adding to this problem is the status of resident fishes, such as bull trout (*Salvelinus confluentus*), which have been listed by the American Fisheries Society as species of special concern throughout their range in Oregon and Washington (Howell and Buchanan 1992, Williams and others 1989).

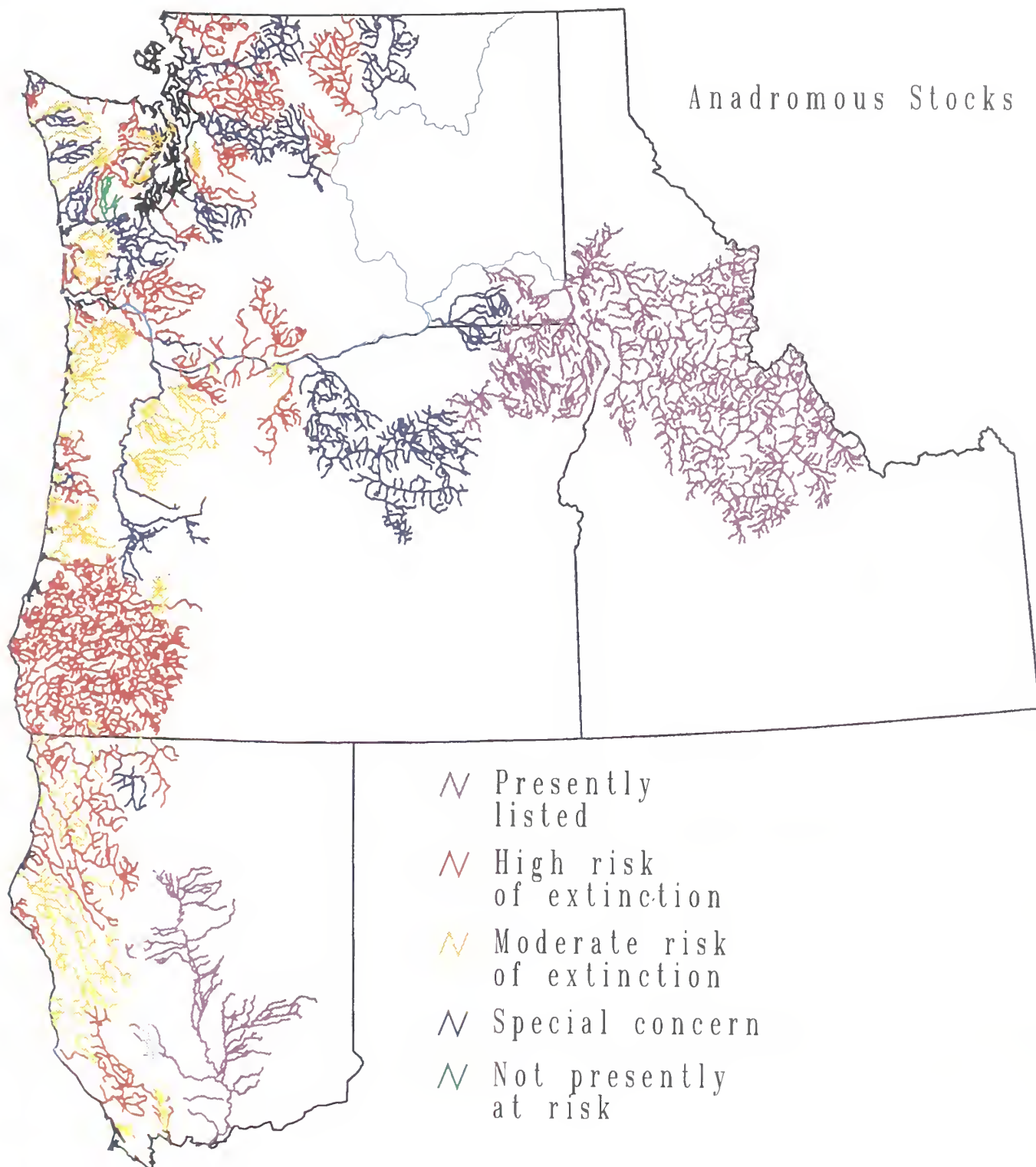
Declines in anadromous salmonid stocks have been attributed predominantly to juvenile and adult mortality from passage through Columbia River dams, habitat degradation, and over exploitation in mixed-stock fisheries (Nehlsen and others 1991, Northwest Power Planning Council 1986). Habitat degradation and the introduction of exotic fishes have been the primary causes of declines in resident fishes (Howell and Buchanan 1992, Williams and others 1989).

The question of forest health, as it is generally perceived, largely focuses on the issue of dead and dying trees. To transcend this perception, management and research must begin to frame the picture of forest health as one of watershed health. Because resident and anadromous fish stocks are at risk throughout the Columbia River basin, research must begin to link the processes that occur along the interfaces between the uplands and the riparian zone (Gregory 1991). The issues include protecting, maintaining, and restoring riparian vegetation, large woody debris, nutrient cycling, sediment dynamics, habitat complexity, water quantity, and water quality. If prescriptions aimed at restoring eastside forests fail to recognize and protect these critical linkages and processes, the health of stream ecosystems and fish populations is sure to continue to decline.

Streams in managed watersheds of eastern Oregon and Washington are in a highly degraded state relative to unmanaged systems. To restore fish habitat to a state that will support self-sustaining fish populations, these streams are in need of less fine sediment, more shade, and increased habitat complexity. Traditional approaches to stream restoration, such as in-stream structures, are at best band-aid measures with a high degree of uncertainty for improvement. To ensure success, management must center around a long-term, holistic approach that protects and maintains ecological processes at the scale of large watersheds (Naiman and others 1992).

This paper documents changes in stream habitat over the past 50 years and examines the current condition of stream habitat in selected river basins of eastern Oregon and Washington. In reviewing changes in stream habitat, we also surveyed, with varying degrees of specificity, changing patterns of land-use, stream-flow, and climate regimes over time. From this overview, we identified watersheds with high-quality fish habitat or a high potential for restoration. Wissmar and others (1993, this volume) give a more general overview of the ecological health of river basins throughout the eastside.

Figure 1 (next page). Status of anadromous fish stocks in the Western United States (Pacific Northwest Research Station 1992; based on Frissell 1990; Johnson and others 1991; and Nehlsen and others 1991).



CHANGES IN FISH HABITAT IN SELECTED EASTSIDE RIVER BASINS OVER THE PAST 50 YEARS

A series of reports published from 1949-1952 by the U.S. Fish and Wildlife Service are the primary basis for current estimates of the loss of anadromous fish habitat in the Columbia River basin. The reports were brief, qualitative accounts of over 8000 km of stream surveys conducted by the Bureau of Fisheries from 1934-46 (Bryant 1949; Bryant and Parkhurst 1950; Fulton, 1968, 1970; Northwest Power Planning Council 1986; Parkhurst 1950a, 1950b, 1950c, Parkhurst and others 1950; Thompson 1976).

The Bureau of Fisheries surveys were undertaken with the objective of determining the condition of streams in the Columbia River basin that provided, or had provided, spawning and rearing habitat for salmon and steelhead (Rich 1948). Recently, the original field notes from the Bureau of Fisheries surveys were discovered. The data are now being archived and stored in the Forest Science DataBank at Oregon State University. These records are the earliest and most comprehensive documentation available on the condition and extent of anadromous fish habitat in the Columbia River basin. They provide the best available data for quantifying change and setting benchmarks for future restoration of anadromous fish habitat throughout the basin.

The Pacific Northwest Research Station has been using the Bureau of Fisheries surveys, in conjunction with current surveys, to determine how the condition of stream habitat in the Columbia River basin has changed over the past 50 years. The Pacific Northwest Research Station study, conducted from 1987 to the present, has examined streams across a broad range of geological conditions, land ownerships, and land-use histories (McIntosh 1992, Sedell and Everest 1990).

More than 1500 km of streams throughout the Columbia River basin have been examined. Preliminary results indicate that the frequency of large pools ($\geq 20 \text{ m}^2$ and $\geq 1.0 \text{ m}$ deep) in streams within managed watersheds decreased by 28 percent over the past 50 years (table 1). Considerable variability was found in the magnitude and direction of change between basins, but pool habitat has decreased. Over the same period, the frequency of large pools has increased in unmanaged watersheds by 77 percent (table 2). The direction for all unmanaged watersheds surveyed was towards improved habitat. Pool loss in managed watersheds, while pools have increased in unmanaged watersheds, indicates that land management activities, such as logging, road construction, livestock grazing, and agricultural practices, have caused this decrease in pools.

Pools and substrate composition are important to anadromous salmonids for all phases of their freshwater life. Pools provide rearing habitat for juvenile fish, resting habitat for adult fish before spawning, and refugia for adults and juveniles from catastrophic events such as drought, fire, and winter-icing (Sedell and others 1990). Substrate composition affects the quantity and extent of spawning habitat, provides summer and winter cover for juvenile fish, and influences aquatic biological production. A considerable body of literature has demonstrated the detrimental effect of fine sediments on salmonid reproduction (for review, see Chapman 1988, Everest and others 1987).

Changes in the pool and substrate composition of stream habitat are also a biodiversity issue. Research on Oregon coastal streams (Reeves and others 1993) has shown that species diversity in logged basins was lower than in similar streams in unharvested basins. The loss of stream habitat diversity from land-use practices has altered fish community composition and reduced species diversity (Bisson and Sedell 1984, Bisson and others 1992, Reeves and others 1993).

For this paper, we will use the Bureau of Fisheries survey to determine changes in fish habitat in four river basins of eastern Washington and Oregon. The Yakima, Wenatchee, and Methow River basins of Washington, will be examined, along with the Grande Ronde River basin in Oregon. We will also evaluate the current level of large woody debris in resurveyed streams.

Table 1. Changes in the frequency of large pools (20 m2 area and 1.0 m deep) for managed portions of selected river basins in the Columbia River Basin from 1935 to 1992.

Frequency of large pools				
	Kilometers surveyed	1935-1945 #/km	1987-1992 #/km	Percent change
Tucannon River, WA	83.8	1.8	4.9	172%
Yakima River, WA	65.5	1.8	3.8	111%
Methow River, WA	146.1	1.8	3.5	94%
Wind River, WA	57.0	4.7	7.9	68%
Abernathy Creek, WA	13.4	3.8	6.1	61%
Wenatchee River, WA	33.6	4.9	7.7	57%
Lewis River, WA	7.7	6.6	9.1	38%
Coweeman River, WA	42.5	5.2	6.6	27%
Elochoman River, WA	34.6	7.7	7.7	NC
Grays River, WA	33.3	8.8	7.7	-13%
Clatskanie River, OR	24.9	7.0	5.9	-16%
Asotin Creek, WA	41.8	2.8	1.8	-36%
Cowlitz River, WA	87.1	13.6	8.1	-40%
Salmon River, ID	185.9	8.8	5.0	-43%
Willamette River, OR	232.3	9.0	4.1	-54%
Lewis and Clark River, OR	16.7	10.3	4.4	-57%
Clearwater River, ID	8.4	4.8	1.7	-65%
Grande Ronde River, OR	157.9	6.1	2.1	-66%
Total	1273.0	7.2	5.2	-28%

Table 2. Changes in the frequency of large pools (20 m2 area and 1.0 meter deep) for wilderness or unmanaged portions of selected river basins in the Columbia River Basin, from 1935 to 1992.

Frequency of Large Pools				
	Kilometers Surveyed	1935-1945 #/km	1987-1992 #/km	Percent Change
Willamette River, OR	1.6	2.5	12.4	396%
Methow River, WA	30.2	1.0	3.4	240%
Wenatchee River, WA	80.2	2.5	6.4	156%
Yakima River, WA	18.8	1.6	3.9	144%
Salmon River, ID	134.2	5.3	6.8	28%
Total	265.0	3.9	6.9	77%

Changes in fish habitat in streams of eastern Oregon and Washington are very similar to the results for the Columbia River basin as a whole. At the time of the Bureau of Fisheries survey, pools were nearly twice as frequent in managed as in unmanaged systems. Currently, the opposite is true. Streams that were recently surveyed in managed watersheds have lost 31 percent of their large pools, and the corresponding figure for unmanaged watersheds is a threefold increase (fig. 2, table 3). Current U.S. Department of Agriculture, Forest Service standards for pools are listed in table 4 (U.S. Department of Agriculture Forest Service 1991). Few of the streams surveyed meet these standards. In the following sections, we will examine the changes in individual river basins to better illustrate these changes.

Figure 2 (next page). Regional pattern of changes in large pool frequencies for selected river basins of eastern Oregon and Washington.

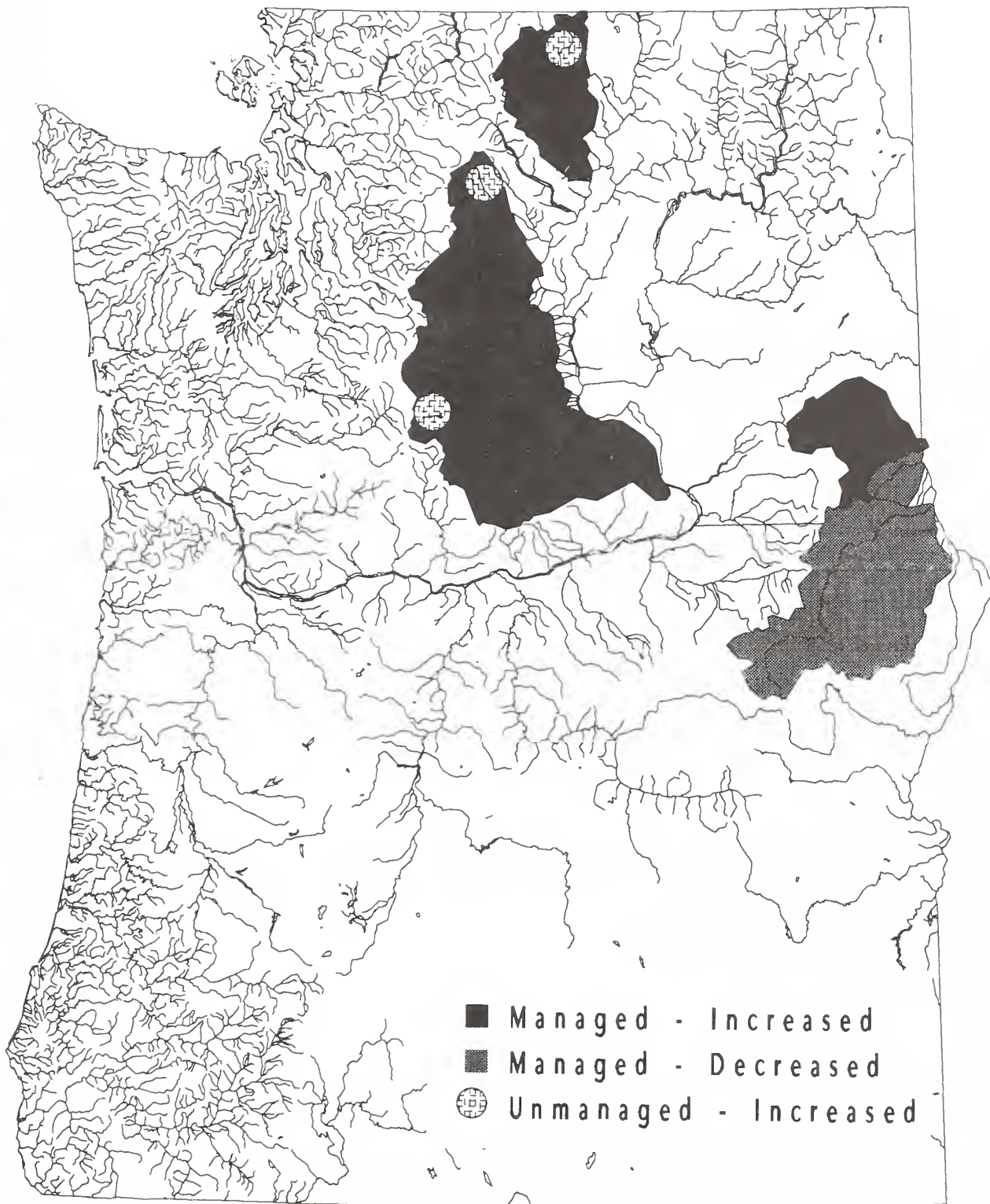


Table 3. Changes in the frequency of large pools in managed and unmanaged portions of selected river basins in eastern Washington and Oregon.

Frequency of Large Pools				
	Kilometers Surveyed	1935-1945 #/km	1987-1992 #/km	Percent Change
MANAGED BASINS				
Tucannon River, WA	83.8	1.8	5.0	178%
Methow River, WA	146.0	1.7	3.4	100%
Yakima River, WA	67.7	1.9	3.2	68%
Wenatchee River, WA	33.6	4.9	7.7	57%
Asotin Creek, WA	41.8	2.8	1.8	-36%
Grande Ronde River, OR	157.9	6.1	2.1	-66%
Total	530.8	4.2	2.9	-31%
Frequency of Large Pools				
	Kilometers Surveyed	1935-1945 #/km	1987-1992 #/km	Percent Change
UNMANAGED BASINS				
Methow River, WA	30.3	1.0	3.4	240%
Wenatchee River, WA	80.0	2.5	7.5	200%
Yakima River, WA	18.8	1.6	3.9	144%
Total	129.1	2.0	6.0	200%

Table 4. U.S. Forest Service standards for large pools in Region 6

A) Alluvial gravel or low gradient streams (< 2%)
standard - streams will have one or more primary pools every 5 to 7 bankfull channel widths.
B) Boulder-rubble or moderately steep gradient streams (> 3%).
standard - streams will have one or more primary pools [a] every 3 bankfull channel widths.
[a] = primary pools occupy 50 percent of the low flow channel width and have a maximum depth 0.9 m

Current Levels of Large Woody Debris for Selected River Basins of Eastern Oregon and Washington

The scientific community generally agrees on the functional role of large woody debris in creating and maintaining high quality fish habitat (Bisson and others 1987, Everest and others 1987, Gregory and Ashkenas 1990, Hicks and others 1991, MacDonald and others 1991). Large woody debris serves a wide array of physical and biological functions in stream ecosystems, which include providing cover and habitat complexity for fish, sediment storage, in-channel roughness, reducing the erosional effects of high flows, and enhancing pool development and maintenance. Many studies have shown that the loss of large woody debris reduces salmonid production (Bisson and others 1987, Everest and others 1985, MacDonald and others 1991).

Unfortunately, the Bureau of Fisheries survey did not collect data on large woody debris for comparison with the current surveys. We collected data that quantifies the number of pieces of large woody debris in a given stream and how it is arrayed, that is: Does it occur as single pieces or as aggregations (≥ 2 pieces)? The survey results indicate that the frequency of large woody debris and debris complexes is about 50 percent greater in unmanaged streams than in managed streams (table 5). Current standards for the Forest Service, Pacific Northwest Region, require more than 60 pieces of large woody debris/km (≥ 0.3 m and ≥ 11.0 m length) in eastside streams. Given that the minimum size for large woody debris in the resurveys is much smaller (≥ 0.1 m diameter and ≥ 2.0 m length) than the regional standard, the resurveys are an overestimate of large woody debris relative to current standards. This further illustrates how little large woody debris is in managed streams.

Table 5. Current amounts of large woody debris (LWD, > 0.1 m diameter and 2.0 m length) in selected managed and unmanaged river basins of eastern Oregon and Washington

Managed Streams			
	LENGTH (KM)	LWD (#/KM)	LWD COMPLEXES (#/KM)
Grande Ronde Basin	148.7	40.0	5.9
Yakima River Basin	8.1	32.8	5.8
Wenatchee River Basin	33.6	26.7	3.5
Methow River Basin	146.1	69.2	12.3
TOTAL	336.5	MEAN 42.2	6.9
Unmanaged Streams			
	LENGTH (KM)	LWD (#/KM)	LWD COMPLEXES (#/KM)
Yakima River Basin	18.8	72.7	13.8
Wenatchee River Basin	80.0	72.5	11.9
Methow River Basin	30.3	40.2	8.1
TOTAL	129.1	MEAN 61.8	11.3

The frequency of large woody debris has decreased in managed systems because of extensive debris removal programs initiated in the 1950s and continued into the 1980s, along with riparian timber harvest (Sedell and others 1991). In addition, the recruitment of large woody debris in managed streams has been greatly reduced by past and present riparian timber harvest. Analysis of current forest practices rules in Oregon and Washington suggest that the future recruitment will decrease with each succeeding rotation (Heimann 1988, Oregon Department of Forestry 1992). The reduction of large woody debris in managed systems contributes to decreased habitat complexity and cover, higher stream temperatures, reduced sediment storage and routing capabilities, and the instability of stream channels and floodplains.

Changes in Fish Habitat—Grande Ronde River Basin, Oregon

In 1990, more than 150 km of streams were resurveyed in the Upper Grande Ronde River basin for comparison with the historical surveys (McIntosh 1992). This survey included more than 70 km of the Grande Ronde River and all major tributaries that provide habitat for spring chinook. From these surveys, McIntosh (1992) documented a loss of more than 65 percent in pool habitat in the Upper Grande Ronde River basin, along with high levels of fine sediments throughout chinook salmon spawning habitat. This work has provided the Pacific Northwest Research Station with its most in-depth overview of the change in anadromous fish habitat in the Columbia River basin.

At the time of the 1941 Bureau of Fisheries survey, the Upper Grande Ronde River basin had experienced considerable human-induced disturbance. The available records of land-use history for the Upper Grande Ronde River basin were examined to characterize and quantify, where possible, land-use practices before and after the 1941 survey. These included records of timber harvest, road construction, and livestock grazing, from various sources. In addition, to provide an overview of land-use practices, more general information on insect outbreaks, splash dams, and mining was also studied and incorporated.

Study Area—The Upper Grande Ronde River basin, in the extreme northeast corner of Oregon, encompasses an area of about 3000 km² (fig. 3). A major tributary of the Snake River, the basin extends 342 km from the headwaters to the mouth; it is characterized by two major drainages, the Grande Ronde River and Catherine Creek.

About 50 percent of the Upper Grande Ronde River basin, mostly mountainous and timbered, is public land managed by the Forest Service. The valley bottoms are predominantly private land used mainly for livestock grazing and agriculture.

Historically, the Upper Grande Ronde River basin had large runs of anadromous salmonids. The basin supported large runs of spring chinook, and summer steelhead (*O. mykiss*) (Northwest Power Planning Council 1990). These fish stocks have been reduced to a small fraction of their predevelopment numbers, with spring chinook listed as threatened under the Endangered Species Act. The declines in productivity have been attributed primarily to juvenile and adult mortality from passage through Columbia River dams, habitat degradation, and over exploitation of mixed-stock fisheries (Northwest Power Planning Council 1986). Within the basin, habitat degradation, both in-channel and riparian, with the attendant high summer and low winter water temperatures is considered the most serious problem. The causes are believed to be stream channelization, livestock grazing, road building, timber harvest, and mining (James 1984, Northwest Power Planning Council 1990, Oregon Department of Fish and Wildlife 1987).

Land use history: mining—Among the first effects of Euro-Americans to the upper Grande Ronde River basin was mining. The headwaters of the basin have been mined for gold since 1870, with extensive dredge mining in the early 1900s. Throughout the headwaters, gold mining has significantly altered the river and its floodplain. Extensive mine tailings from dredging occur throughout the upper sections, constricting the channel and providing a continuous source of sediment. When this section was surveyed in 1941, the surveyors noted that:

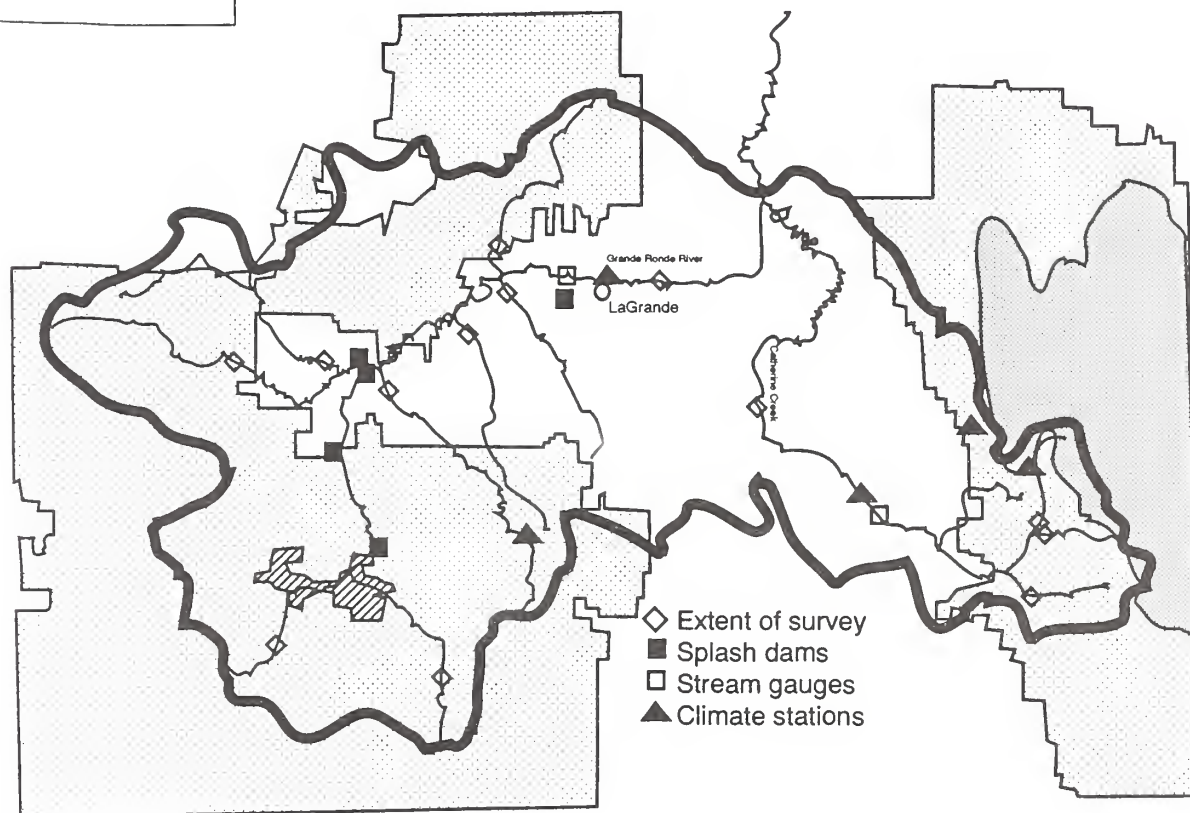
The operations of the Indiana Mine have certainly raised havoc with the upper portions of the river. In a great many instances the river is present in sound only. It was possible, at the time of the survey, to drive a car up the middle of the stream bed. What was left of the river was flowing, out of sight, underneath the rubble. Dredging and filling has put the rubble on top of the water. At any rate they have left a monument that will remain a dirty blot on the landscape for years to come.





(field notes from 1941 Bureau of Fisheries survey).

Ironically, because the tailings are a part of a national historic site, they are off-limits to alteration or channel rehabilitation. At the same time, this reach of the river also provides the majority of the spring chinook spawning habitat in the upper Grande Ronde.



UPPER GRANDE RONDE RIVER BASIN



-  National Forest
-  Wilderness Area
-  Private land
-  Watershed boundary

Drainage area: 3000 km² (1150 mi²)

Livestock grazing—Early records of livestock grazing in the Upper Grande Ronde basin suggest that the area had been overgrazed by the 1880s (Skovlin 1991). Records of actual grazing use were available from the Wallowa-Whitman National Forest, covering the period 1911 to 90. Over that period, grazing use by domestic livestock (cattle and sheep) declined 78 percent (fig. 4), largely from the collapse of the sheep industry in northeast Oregon (J. Anderson, pers. comm.). Cattle grazing now constitutes more than 90 percent of grazing use from domestic livestock.

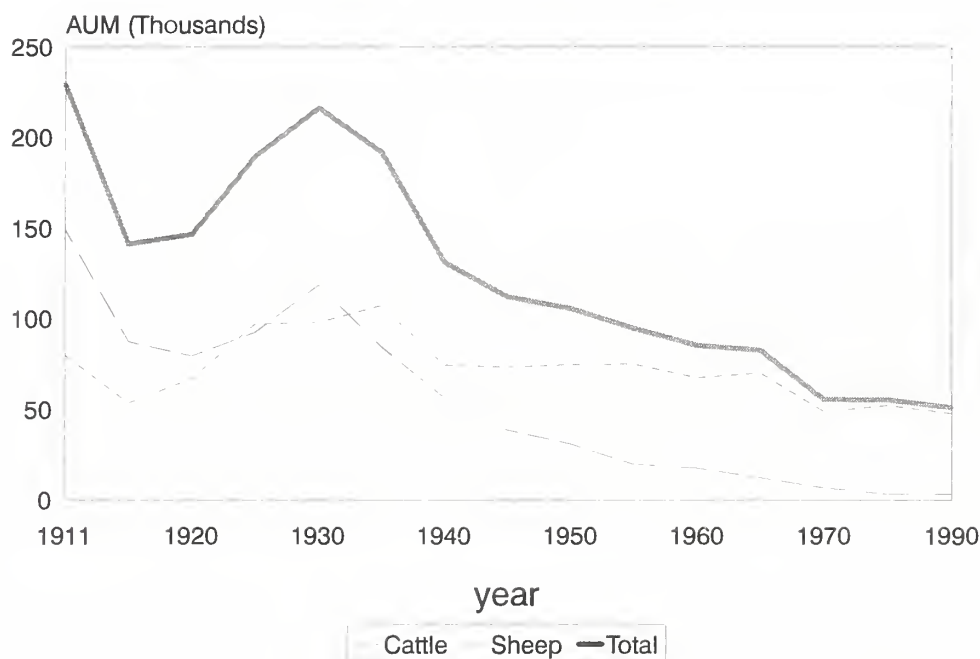


Figure 4. Grazing use (animal unit month) by livestock on the Whitman portion of the Wallowa-Whitman National Forest, 1911 to 1990.

While grazing by domestic livestock has been declining, grazing use by elk appears to have increased. Elk populations were very low during the early part of the century because of overhunting. In 1919, elk hunting was closed and intensive efforts were begun to rebuild the herds. Records of grazing use by elk began to be kept in 1965. Data before that is based on estimates. These countervailing trends suggest that grazing intensity has stayed fairly constant since 1945 (fig. 5), although the effects of livestock and elk grazing may be different.

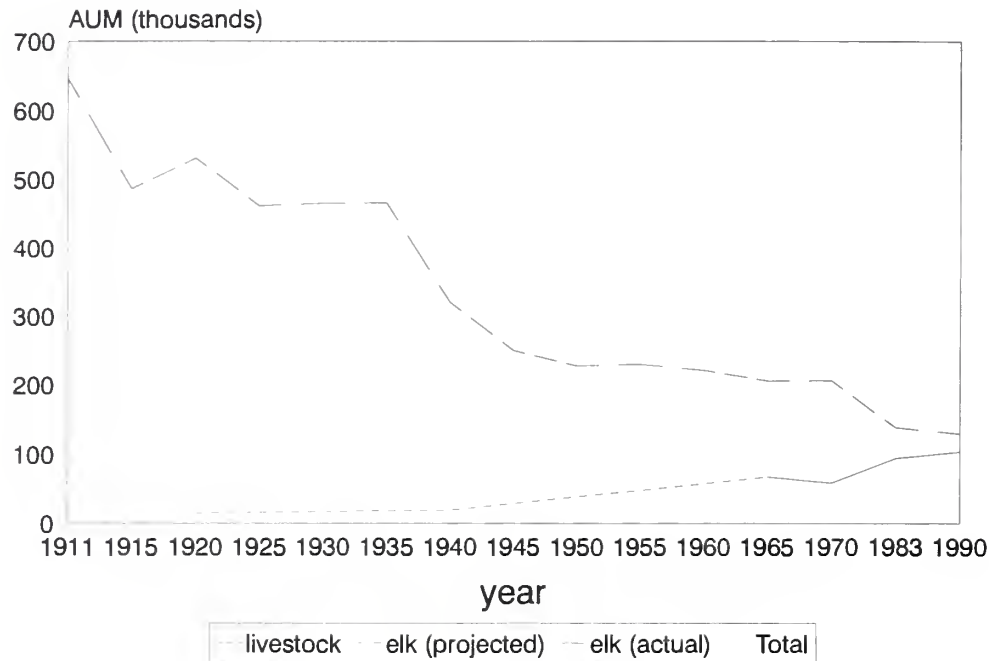


Figure 5. Grazing use (animal unit month) by livestock and elk on the Wallowa-Whitman National Forest, 1911 to 1988.

Timber harvest—The historical records of timber harvest in the Upper Grande Ronde River basin, indicate that logging began in the late 1880s (Farnell 1979). Harvest rates have varied from 1896 to 1990, but show a steadily increasing trend (fig. 6). Timber harvest averaged 36 million fbm/year before the 1941 survey (1896 to 1940) and increased to 98 million fbm/year from 1941 to 90, an increase of 172 percent. Although harvest rates have increased over time, the spatial patterns of harvest must also be considered. Ownership patterns (fig. 3) show that the Forest Service manages higher elevation and headwater portions of the basin, and the lower elevations are private land. Harvest in the early part of the century was restricted to riparian areas and the adjacent hillslopes. In the latter part of the century, higher elevation and headwater sections of the basin were accessed and logged as road construction increased.

In the early 1900s, logging was largely limited to private lands in the basin. Before the coming of the railroad and the building of roads, from the late 1800s to 1919, the Grande Ronde River was a major log-driving river. Splash dams were built on the Grande Ronde River at Perry and at Vey Meadows, on Dark Canyon, Meadow, and Fly Creeks (fig. 3) to provide sufficient flow to drive logs at all seasons (Farnell 1979). Splash damming and associated log drives are believed to have had devastating effects on all forms of aquatic life, along with causing considerable damage to the stream channel (Sedell and others 1991).

By 1919, the Union Pacific Railroad had extended its tracks to the upper portions of the basin, encompassing the Grande Ronde River and all the major tributaries. The improved access allowed for more reliable delivery of timber, eliminating the need for splash dams and log drives. As the railroad extended its reach up the basin, more areas became accessible (Farnell 1979). The railroads were used until 1954. Old railroad grades are visible throughout the basin, in most places either adjacent to the stream channel or within the floodplain. These grades serve as artificial geomorphic controls, constraining the stream channel and truncating floodplain processes and functions.

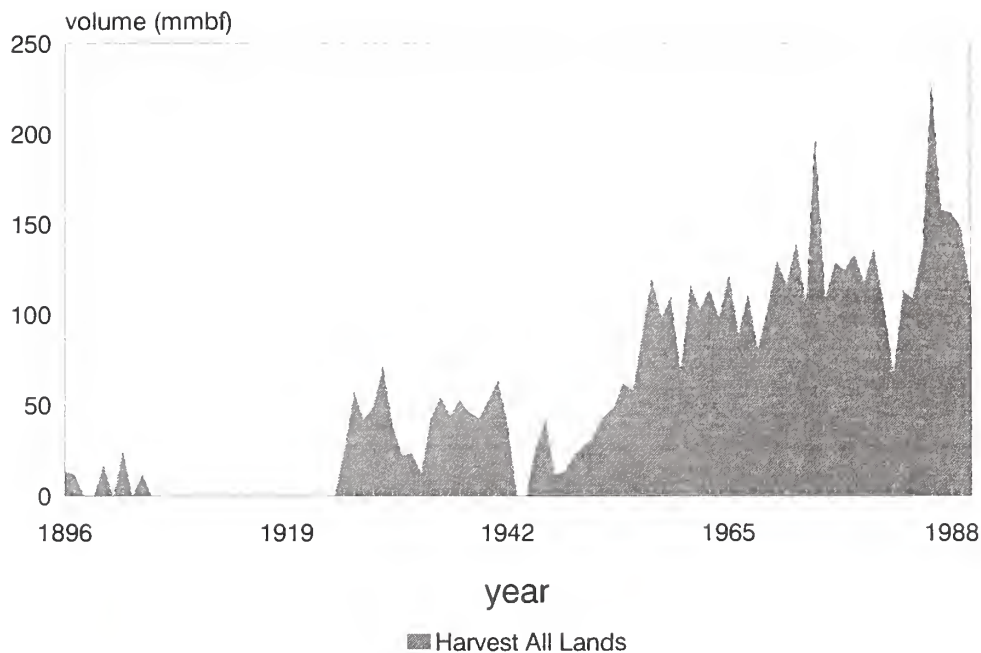


Figure 6. Volume of timber harvested (mmbf) for Union County, Oregon, all land ownerships, 1896 to 1990.

Until the late 1940s, the Forest Service harvested little timber on the Wallowa-Whitman National Forest. In response to insect outbreaks, intensive salvage logging began in the late 1950s. By 1960, harvest was about evenly split between public and private lands. The trend from the 1950s to 1989 has been for increasing rates of timber harvest (fig. 7).

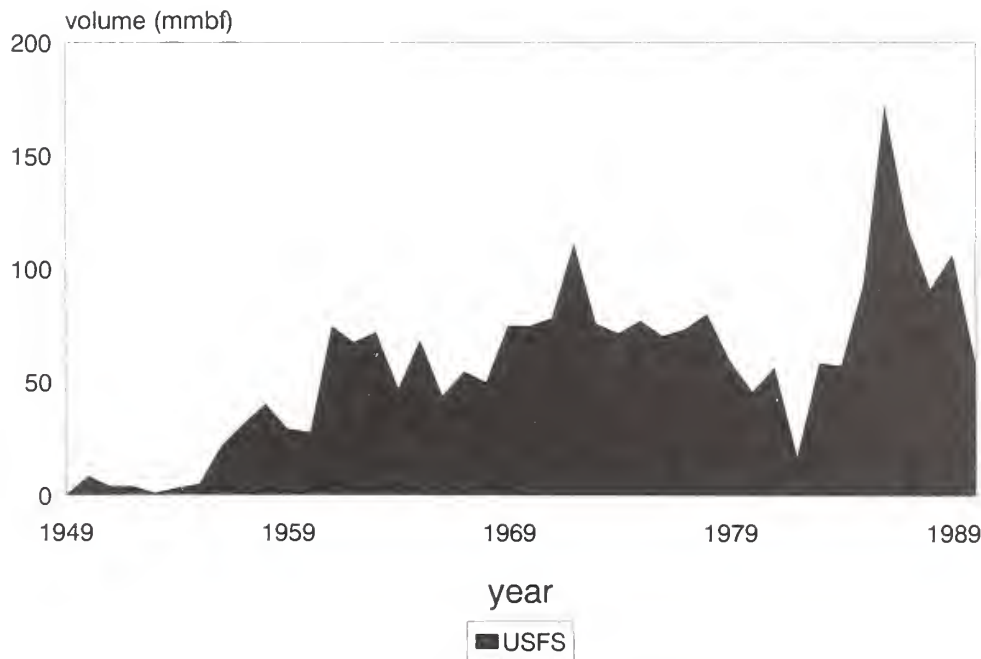


Figure 7. Volume of timber harvested (mmbf) on public land, Union County, Oregon, 1949 to 1989.

Road construction—Road building activities have followed the same pattern as timber harvest (fig. 8). According to Farnell (1979), road construction was minimal until the 1920s because timber was being harvested close to the Grande Ronde River and its tributaries. When the Forest Service began salvage operations in the late 1950s, road building began in earnest. The number of kilometers of roads increased steadily from 1957 to 1978 and, from 1978 to 1989, it more than doubled, from 7200 to 16,000 km. Road densities in the Upper Grande Ronde, as reported by the Wallowa-Whitman National Forest, average 2.5 km/km² for the basin and 4.4 km/km² when roadless areas are excluded. Along the Grande Ronde and most of its tributaries, roads have encroached upon the channel or the floodplain and have greatly constricted the channel's ability to interact with the floodplain.

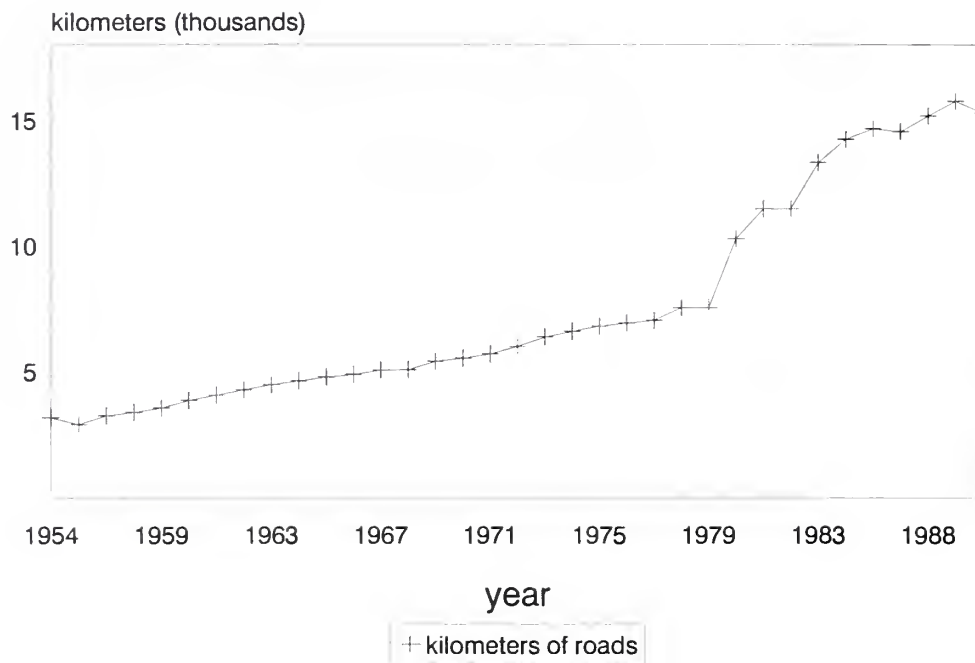


Figure 8. Road mileage (kilometers) on the Wallowa-Whitman National Forest, 1954 to 1990.

Stream channelization—The influences of stream channelization are also evident in the Upper Grande Ronde basin. Stream channelization projects were conducted by the Soil Conservation Service, Bureau of Reclamation, and the Union County Soil and Water Conservation District. The projects attempted to protect private property from flooding by “locking” the stream channel in place with riprap and levees. The periods of most intensive activity were often in response to major floods, such as the 1964 flood.

The McCoy Meadows area in the Upper Grande Ronde is illustrated in figure 9. McCoy Creek was channelized in response to the 1964 flood, as shown in the abrupt transition from the 1964 pre-flood photograph to the 1970 photo. What was once a highly complex and dynamic meadow stream ecosystem has been degraded to a single stream channel, isolated from any interaction with its floodplain. The area above the road (middle of picture) was channelized between 1970 and 1980.

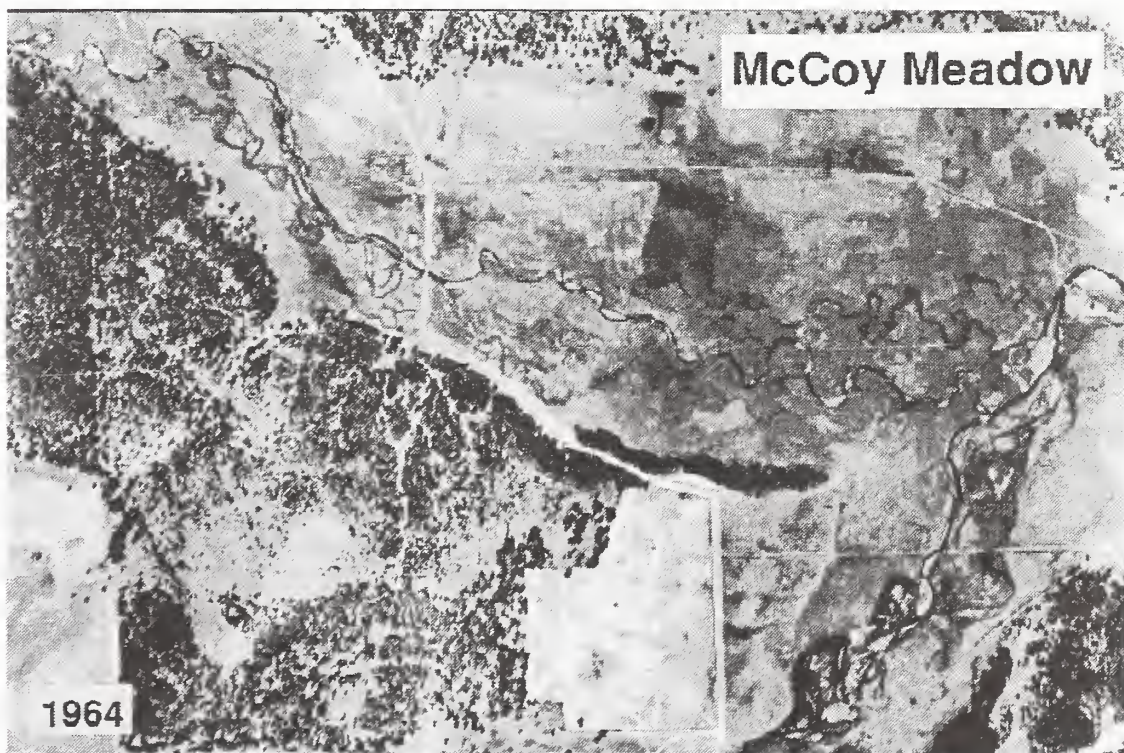
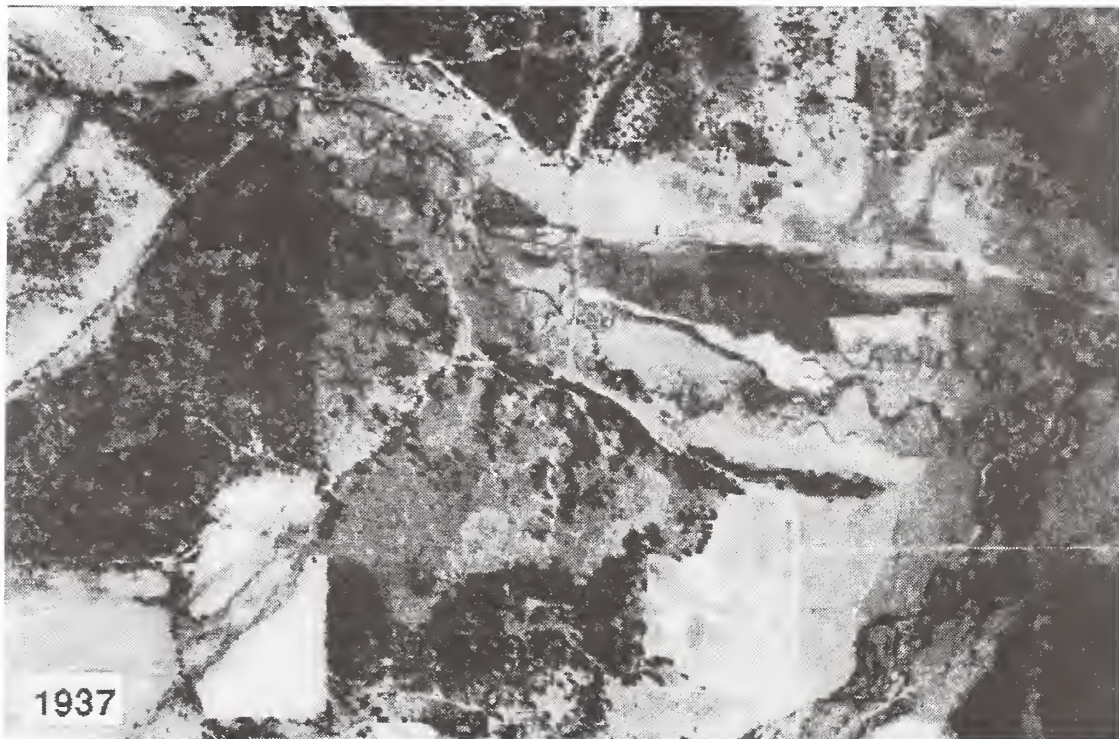


Figure 9. Time sequence of aerial photographs for McCoy Meadows, from 1937-1980, showing the effects of stream channelization.

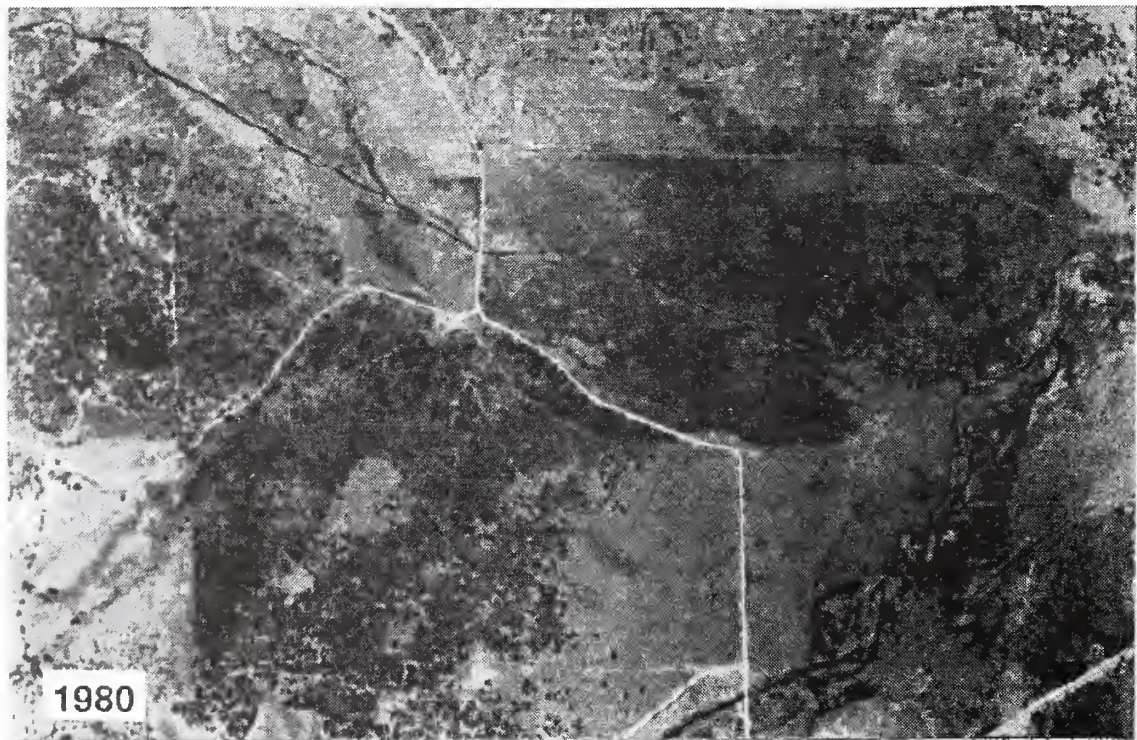


Figure 9. (cont.) Time sequence of aerial photographs for McCoy Meadows, from 1937-1980, showing the effects of stream channelization.

Insects and disease—The history of insect and disease outbreaks and their effect on forest health is well documented for the Blue Mountains of northeast Oregon (Wickman 1991). Repeatedly, over the course of this century, a variety of insects have attacked millions of acres of forestland in northeast Oregon, leaving a landscape suffering declining forest health on what Wickman termed “a mega scale.”

Changes in fish habitat in the Upper Grande Ronde River basin from 1941 to 1990: pool habitat—Analyses of changes in pool habitat were based on large pools ($\geq 20 \text{ m}^2$ area and $\geq 0.8 \text{ m}$ depth) and total pools ($\geq 20 \text{ m}^2$ area and $\geq 0.5 \text{ m}$ depth).

In 1941, the frequencies of total pools/km for the Grande Ronde River and associated tributaries were diverse, ranging from 3.8 to 26.2/km (mean = 12.2/km, table 6). In 1990, pool frequencies ranged from 1.4 to 7.4/km (mean = 4.3/km, table 6). The loss in total pools/km ranged from 43 to 83 percent (table 6), with a mean of 65 percent. One stream, Five Points Creek, stayed the same, but the 1941 survey had indicated that this tributary was already in poor condition at the time of the survey. In 1941, pool frequencies were highly variable among the different streams, but the 1990 survey showed that pool frequencies were similar for all streams.

Table 6. Changes in the frequency of total pools for surveyed streams in the upper Grande Ronde River Basin, 1941 to 1990.

	Kilometers	1941	1990	Percent
Managed Watersheds	Surveyed	#/km	#/km	Change
Five Points Creek	2.8	3.8	3.8	NC
N Fk Catherine Creek	6.6	5.6	3.2	-43%
Rock Creek	2.2	12.0	6.4	-47%
Meadow Creek	18.6	7.3	3.5	-52%
S Fk Catherine Creek	3.3	11.8	4.9	-59%
Catherine Creek	30.7	12.7	4.2	-67%
Jordan Creek	3.1	26.2	7.4	-72%
McCoy Creek	4.7	19.1	5.1	-73%
Grande Ronde River	73.4	6.3	1.4	-78%
Beaver Creek	3.3	16.9	2.8	-83%
TOTAL	157.9	12.2	4.3	-65%

Changes in the frequency of large pools showed a pattern similar to the pattern for total pools. In 1941, large pool frequencies ranged from 0.0 to 14.9/km (mean = 6.2/km, table 7). The frequency of large pools ranged from 0.0 to 7.0 (mean = 2.0/km, table 7) in 1990. This frequency represents a loss of large pools from 20 to 87 percent, with a mean of 66 percent. Five Points Creek and Jordan Creek showed no change, and Rock Creek showed a slight improvement (0.0 to 0.9 large pools/km). A substantial decrease occurred in the variability of large pool frequencies from 1941 to 1990, further emphasizing the trend towards less diverse stream habitat.

Substrate composition—The trend in substrate composition in the Upper Grande Ronde River basin was towards finer substrates (table 8). Even in those streams where the dominant substrate did not change, smaller substrates substantially increased (table 9). With the tributaries channeling finer substrates to the main channel, substrate composition is changing throughout the basin. Changes in the size of substrate indicate a shift in the particle size of bedload transported by the stream (Heede 1980).

The analysis of mean substrate composition indicated no change in fine sediments in the Upper Grande Ronde River and substantial decreases in Catherine Creek. To detect changes in the spatial distribution of fine sediments over time, the percentages of surface fines for individual channel units were plotted from the downstream to upstream extent of the Upper Grande Ronde River.

Table 7. Changes in the frequency of large pools for surveyed streams in the Grande Ronde River Basin 1941 to 1990.

	Kilometers	1941	1990	Percent
Managed Watersheds	Surveyed	#/km	#/km	Change
Rock Creek	2.2	0.0	0.9	90%
Jordan Creek	3.1	0.0	0.0	NC
Five Points Creek	2.8	1.8	1.8	NC
Meadow Creek	18.6	2.5	2.0	-20%
Sheep Creek	9.2	14.6	6.8	-53%
Catherine Creek	30.7	9.2	3.6	-61%
N Fk Catherine Creek	6.6	4.7	1.7	-64%
Grande Ronde River	73.4	4.0	1.1	-73%
McCoy Creek	4.7	9.1	1.7	-81%
Beaver Creek	3.3	10.0	1.5	-85%
S Fk Catherine Creek	3.3	11.2	1.5	-87%
TOTAL	157.9	6.1	2.1	-66%

Table 8. Changes in dominant substrate for surveyed streams in the Grande Ronde River Basin, 1941 to 1990.

Stream	1941 Dominant Substrate	1990 Dominant Substrate	Change
Rock Creek	MR (47%)	MR (35%)	NC
Jordan Creek	MR (48%)	SR (43%)	-
Five Points Creek	MR (43%)	MR (36%)	NC
Meadow Creek	MR (45%)	SR (39%)	-
Catherine Creek	MR (29%)	MR (34%)	NC
N Fk Catherine Creek	MR (35%)	MR (41%)	NC
Grande Ronde River	MR (41%)	SR (39%)	-
McCoy Creek	MR (43%)	MR (45%)	NC
Beaver Creek	MR (46%)	MR (35%)	NC
S Fk Catherine Creek	MR (38%)	LR (38%)	+

MR = medium rubble, SR = small rubble, NC = no change, - = decrease

Table 9. Shift in the percentage of bottom substrate composition for surveyed tributaries of the Upper Grande Ronde River, above La Grande, 1941 and 1990

	1941		1990	1941		1990
Stream	SR	SR	Change	MR	MR	Change
Five Points Creek	21%	33%	+	43%	35%	-
Rock Creek	18%	29%	+	47%	34%	-
Jordan Creek	37%	47%	+	47%	27%	-
Beaver Creek	23%	30%	+	46%	34%	-
Meadow Creek	22%	41%	+	46%	35%	-
McCoy Creek	26%	43%	+	41%	46%	+

SR = small rubble, MR = medium rubble

This spatial analysis indicated that surface fines (MS, < 6 mm) in the headwater portions of the Upper Grande Ronde River exceed 20 percent of the substrate composition throughout most of this reach. Throughout the headwaters, most of the stream channels are highly embedded, generally exceeding current standards of 35 percent (P. Boehne, pers. comm.). Generally, these conditions are recognized as being detrimental to salmonid reproduction (Everest and others 1987). The surface fines detected in the 1990 survey may have been the result of a fire and flash flood event in 1989 that introduced a substantial volume of fine substrates into the stream channel.

Current status of large woody debris—The amount of large woody debris in resurveyed streams varied widely, ranging from 1.0 to 66.0 pieces/km (table 10), with large woody debris generally lacking. In addition, current Forest Service surveys indicate that streams in managed watersheds throughout the upper Grande Ronde have a low frequency of large woody debris, but unmanaged portions of the basin have much higher frequencies (P. Boehne, pers. comm.). The frequency of large woody debris in the upper Grande Ronde is similar to other managed river basins we surveyed on the eastside, but far less than that found in unmanaged systems.

Table 10. Current levels of large woody debris (LWD, ≥ 0.1 m diameter and ≥ 2.0 m length) in selected streams of the Upper Grande Ronde River Basin.			
Managed Streams			
NAME	LENGTH (KM)	LWD (#/KM)	LWD COMPLEXES (#/KM)
Jordan Creek	3.1	1.0	0.6
Rock Creek	2.2	6.0	1.3
McCoy Creek	4.7	6.2	1.4
Grande Ronde River	73.4	14.6	1.9
Five Points Creek	2.8	23.3	3.6
Catherine Creek	30.7	52.0	8.0
Beaver Creek	3.3	59.0	10.1
N Fk Catherine Creek	6.6	65.6	13.4
Meadow Creek	18.6	65.8	
S Fk Catherine Creek	3.3	66.0	12.5
TOTAL	148.7	MEAN 40.0	5.9

Changes in streamflow and climate over time in the Grande Ronde River basin: introduction—To provide context for the changes in anadromous fish habitat in the Upper Grande Ronde River basin, McIntosh (1992) examined the available long-term stream discharge and climate records for the basin. In a given basin, the pattern of runoff can influence the availability and quality of fish habitat. The natural discharge regimes of a watershed, and their interaction with the riparian/stream channel complex, are the processes that create and maintain fish habitat. Changes to these discharge regimes can affect fish habitat and populations adversely. Of particular concern are peak flows, the timing of peak flows, and low summer flow.

Analysis of long-term stream discharge records—Discharge records from the La Grande, Union, and Rondowa gauging stations were analyzed for the period of record to determine trends in annual, peak, and base discharge, along with the timing of peak discharges (McIntosh 1992). The La Grande and Union gauges measure primarily undiverted, natural streamflows, while the Rondowa gauge is influenced by irrigation withdrawals upstream.

Annual discharge was based on mean annual discharge. The instantaneous annual peak discharge was determined from peak flow files provided by the U.S. Geological Survey. These values represent the single largest event in each water year. Base discharge was calculated from the mean of the 10 lowest continuous days for the water year. The timing of peak discharge was based on the Julian day on which the largest peak occurred. Linear regression was used to determine temporal trends in the stream discharge record.

Our analysis showed that base discharge had increased in both the Upper Grande Ronde River (La Grande gauge) and Catherine Creek (Union gauge). The trend line suggests a near doubling in base discharge for the Upper Grande Ronde River (0.4 to 0.75 m³/s (cms), fig. 10), and a 25 percent increase in Catherine Creek (0.56 to 0.70 cms, fig. 11). The timing of peak flows appears to have shifted to earlier in the year in the Upper Grande Ronde River by as many as 30 days (fig. 12, April 10 to March 11). No significant changes were found in the magnitude of peak flows and annual discharge at either gauge.

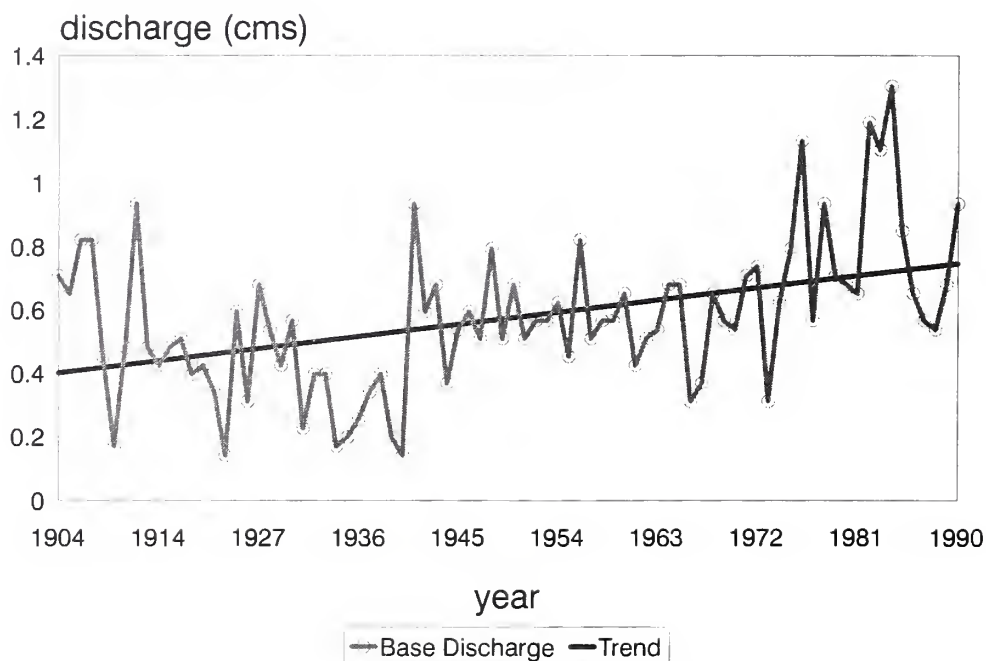


Figure 10. Trend in base discharge for the Upper Grande Ronde River, 1904 to 1990.

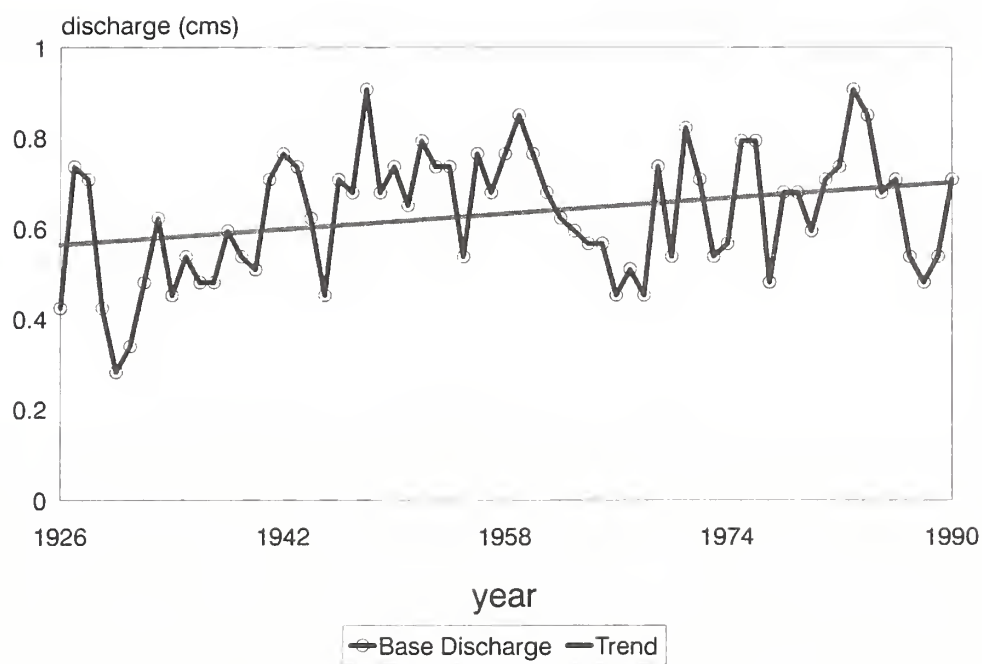


Figure 11. Trend in base discharge for Catherine Creek, 1926 to 1990.

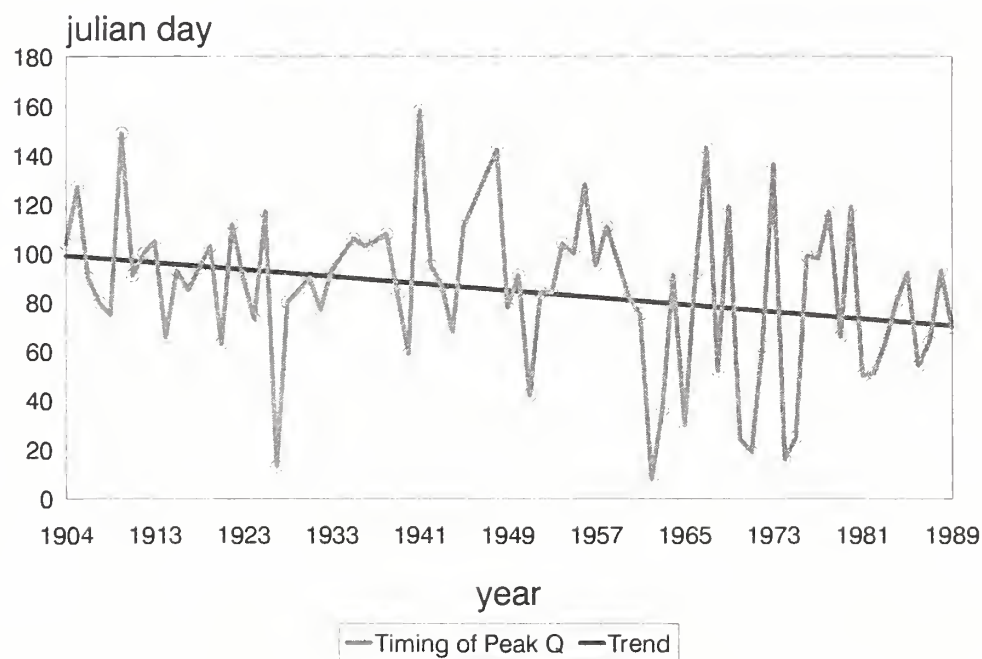


Figure 12. Trend in the timing of peak discharge based on Julian day for the Upper Grande Ronde River, 1904 to 1989.

At the Rondowa gauge, no significant trends appeared in any discharge variables, which would indicate that the changing discharge regimes evident in the Upper Grande Ronde River and Catherine Creek subbasins are unique to that portion of the basin. The data from the Rondowa gauge are influenced by upstream irrigation withdrawals, to what extent this affects the analysis is unknown.

Analysis of long-term climate records—The climate record was examined by using data from all available stations. From these data, mean annual, summer (May-September), and winter (December-May) precipitation, along with snowpack and annual temperature, were calculated. In northeastern Oregon most precipitation comes from winter snowpack, with little precipitation falling during the summer months (Higgins and others 1989).

In the Upper Grande Ronde River basin, mean annual precipitation declined 15 percent and mean annual winter precipitation declined 20 percent over the period of record (figs. 13, 14). Winter snowpack also decreased over 25 percent for the available record (1938 to 1990, fig. 15). No significant changes in summer precipitation or annual temperature were recorded. For the Catherine Creek basin, no significant changes were found in any of the climate variables.

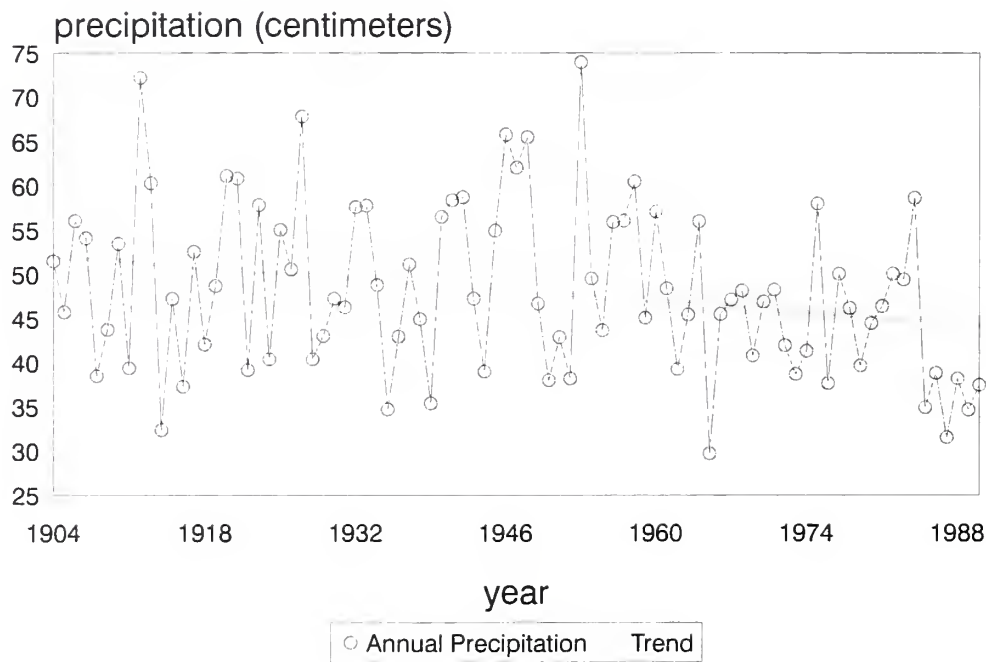


Figure 13. Trend in mean annual precipitation at La Grande, 1904 to 1990.

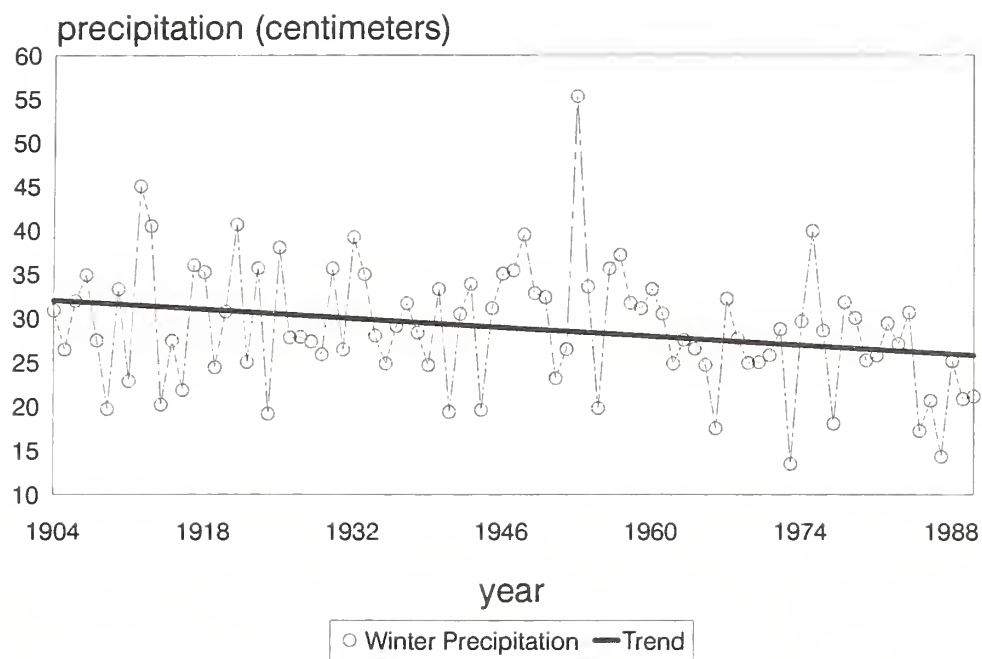


Figure 14. Trend in winter precipitation (December-May) at La Grande, Oregon, 1904 to 1990.

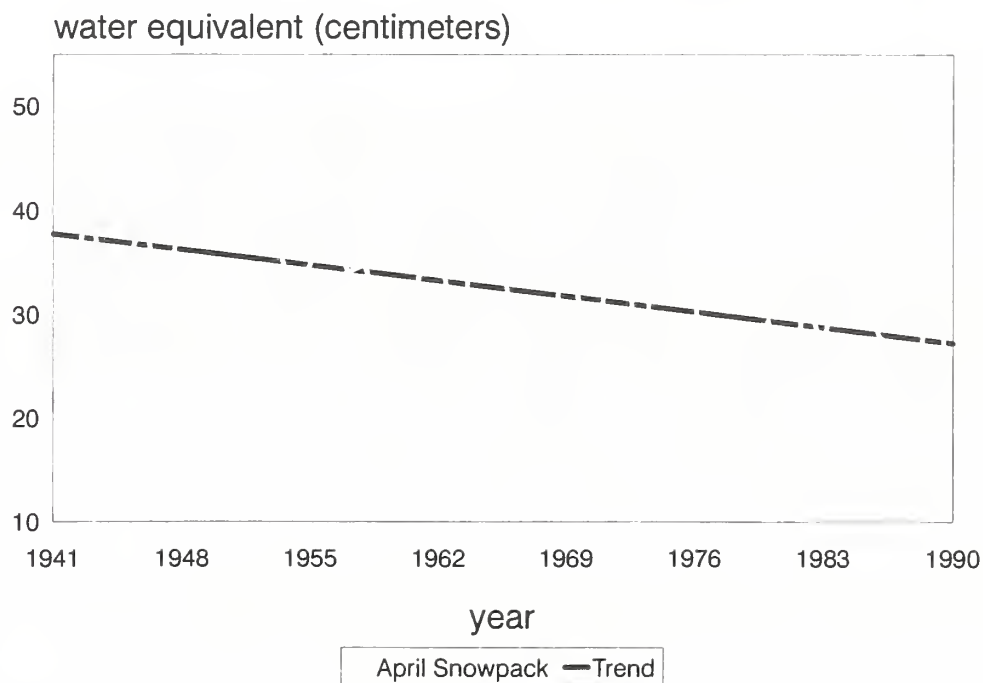


Figure 15. Trend in snowpack (April 1 water equivalent) for Upper Grande Ronde River watershed, at Beaver Creek, 1941 to 1990.

Conclusion—Temporal analysis of streamflow and climate records indicate significant changes in these parameters since 1904. Base discharge has increased, and both annual and winter precipitation, along with snowpack, have decreased. The timing of peak discharge appears to have shifted to earlier in the year.

The near doubling in base discharge, while precipitation has declined, suggests that the increases are not due to climate. The altered base-discharge regime may be the result of reduced evapotranspiration, caused by extensive defoliation from insect infestations and timber harvest. The reduction in moisture lost to transpiration caused by decreased leaf area from insect defoliation and timber harvest could result in more precipitation being retained as soil moisture, eventually being released to the stream channel through subsurface flow. The higher base discharge did not translate into increased annual discharges, but still showed a significant increase during a critical bottleneck in anadromous salmonid life history. Base flow may be more sensitive to increased subsurface flow than annual discharge because base flow is less than 3 percent of the annual water yield.

Change in the timing of peak discharge to earlier in the year could also be a result of land use practices. Research in western Oregon has shown that snowfall accumulations are greater in clearcuts and that they melt earlier because of increased exposure to solar radiation (Harr 1983). The high rate of timber harvest in the Upper Grande Ronde River basin may have created similar conditions.

The shift in timing of peak flows may have implications for the emigration of smolts from the basin, since their migration is timed largely to peak flows. If the smolts are forced to migrate earlier, they may not be physiologically ready, or if they do not migrate early, they risk being stranded by low flows. The migration of smolts is a highly evolved process that represents a critical juncture in the life history of anadromous salmonids.

Conventional wisdom holds that the rearing capacity of streams in eastern Oregon is limited by base discharge. A similar analysis of long-term base flow trends for the John Day River basin indicates that base flows have also increased in all river basins with gauging stations except one (PNW, unpublished data). The exception was Strawberry Creek, draining the Strawberry Mountains wilderness area, which showed no change in base flow. Preliminary analysis of other major river basins in eastern Oregon and Washington have shown no increase in base flow. This phenomenon appears to be limited to the Blue Mountain region.

The increased base discharge in the Upper Grande Ronde River may indicate sufficient summer flow, but both in-channel (pools) and floodplain (riparian vegetation), habitats necessary to store and release these increased base flows over the summer are not functional (Elmore and Beschta 1987, Sedell and Beschta 1991).

Summary—From this historical perspective on how anadromous fish habitat has changed, we can begin to identify desired conditions and opportunities for restoration. Pools are not distributed evenly along the stream network, but tend to occur in patches. Most pool habitat, both historical and current, is in unconstrained reaches, providing the geomorphic context to habitat distribution. Unconstrained reaches are defined as having a valley floor width greater than two active stream channel widths. For example, 40 percent of the Grande Ronde River is unconstrained. In 1941, these reaches contained 69 percent of the pool habitat, declining to 48 percent by 1990.

Unconstrained reaches are the most dynamic, complex, and productive portions of the riverine environment (Gregory and others 1991, Sedell and others 1990.). These habitats are the result of highly dynamic interaction between the stream channel and the associated floodplain and riparian vegetation. Research in western Oregon has shown that unconstrained reaches have the highest biotic productivity (Gregory and others 1989, Lamberti and others 1989, Moore and Gregory 1989).

To expedite recovery of stream and riparian habitat, thus improving anadromous fish habitat, recovery efforts for the near-term should be focused on unconstrained reaches. These areas will recover fastest, with accompanying increases in biological productivity. Efforts should focus on restoring and enhancing the natural processes that cause these reaches to be so highly dynamic, complex, and productive.

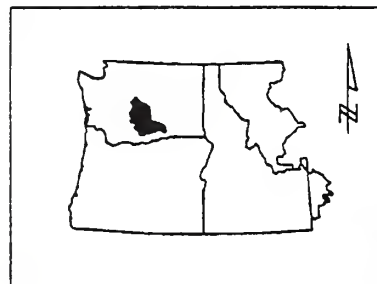
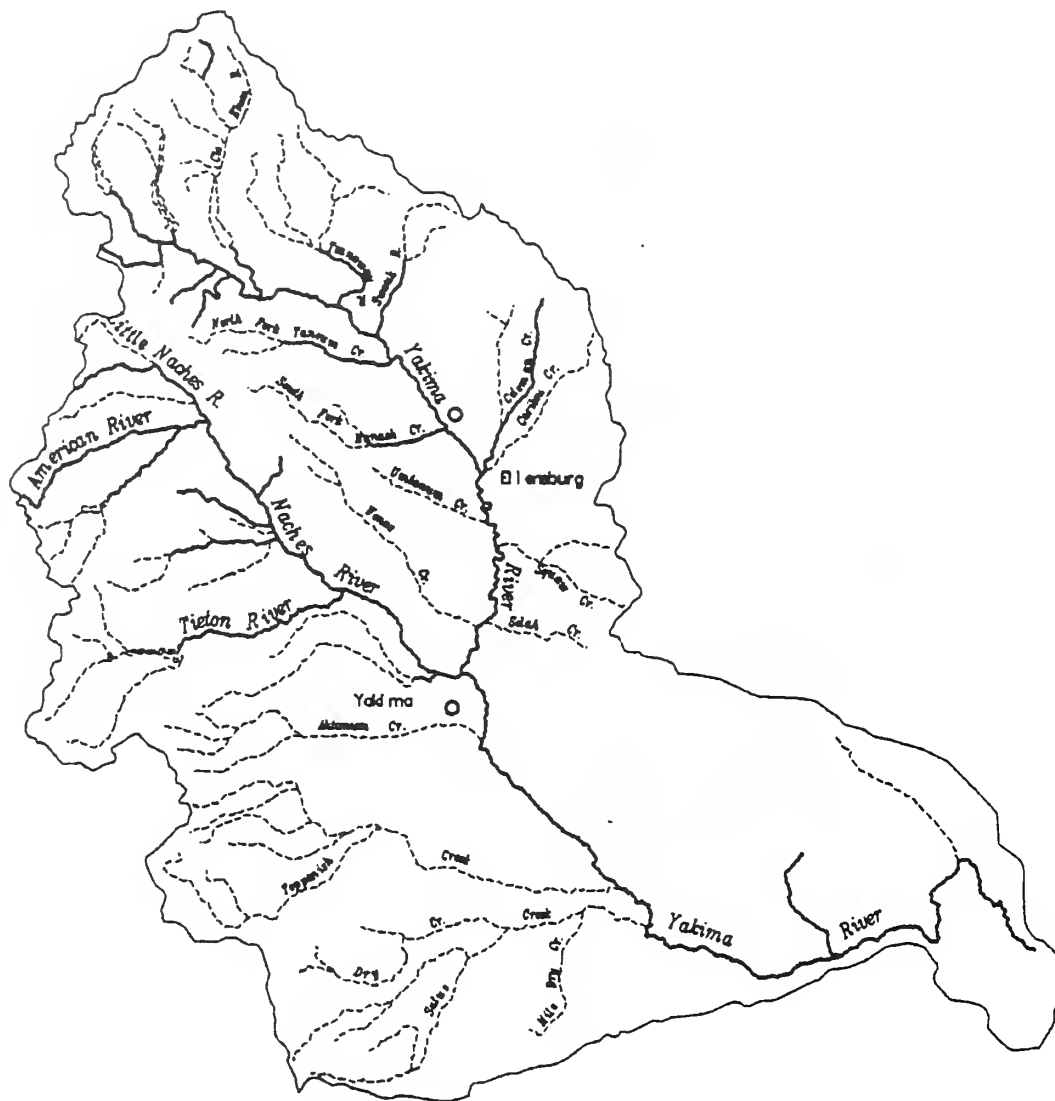
Restoring stream and riparian habitat in the Grande Ronde River basin requires changes in land management practices and a long-term commitment to good watershed stewardship. A framework for restoration has been developed in the Upper Grande Ronde River Anadromous Fish Habitat Protection, Restoration, and Monitoring Plan (Anderson 1992). In the near-term, anadromous fish stocks need relief from highly unfavorable rearing and spawning conditions. Management should emphasize accelerating recovery through sound and biologically defensible methods. These efforts should concentrate on areas most important to rearing and spawning and should in no way forestall the long-term recovery of the Upper Grande Ronde River.

Changes in Fish Habitat—Yakima River Basin, Washington

From 1990 to 92, the Pacific Northwest Research Station cooperated with the University of Washington and the Wenatchee National Forest to resurvey over 80 km of historically surveyed streams in the Yakima River basin. Three streams within the Naches River basin, and one tributary of the upper Yakima River were resurveyed. Pool habitats have increased in both managed and unmanaged drainages over the past 50 years. Of the four streams we surveyed, only the American River had a decrease in pool habitat.

Study area—The Yakima River basin, in south-central Washington, drains an area of 15,942 km² (fig. 16). It is the largest tributary of the Columbia River in Washington. The Yakima River's headwaters are near the crest of the Cascades above Keechelus Lake; the river flows 344 km to the southeast, emptying into the Columbia River. Six major reservoirs and several major diversion dams are on the Yakima and Naches Rivers (Northwest Power Planning Council 1989). More than 60 percent of the land in the Yakima basin is publicly owned, with the remainder in private ownership. The Yakima Indian Reservation, in the southwest portion of the basin, comprises 25 percent of the land base. Irrigated agriculture is the economic base of the basin, with livestock production and forestry also contributing to the local economies (Northwest Power Planning Council 1989).

YAKIMA SUBBASIN



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Figure 16. Yakima River basin, Washington

The Yakima basin once supported spring, summer/fall chinook, summer steelhead, coho (*O. kisutch*), and sockeye salmon. Historic runs have been estimated at 790,000 adults before the 1870s (Northwest Power Planning Council 1989, table 11). By the turn of the century, more than 90 percent of the runs were believed to be depleted, with coho and sockeye runs nearly extinct (Uebelacker 1980). The primary causes were dams and irrigation canals without adequate fish ladders and screens, along with log drives that affected stream habitat, and local overfishing (Fast and others 1991). These declines were not taken seriously by management agencies until the 1950s. In addition, resident trout and bull trout were also declining.

Table 11. Historical estimates of salmon and steelhead runs in the Yakima River basin (NPPC 1989).

Species/race	Historic Run Size	Present Run Size [a]
Spring Chinook	200,000	
Fall & Summer Chinook	200,000	
Coho	110,000	
Summer Steelhead	80,000	
Sockeye	200,000	
Total	790,000	7,018

[a] - based on mean run size for all anadromous salmonids in the Yakima Basin, from 1983-87 (NPPC, 1989). Sockeye and summer chinook are extinct, with coho at severely depressed populations.

Within the basin, the major constraints currently limiting increased anadromous fish runs are believed to be inappropriate instream flows (too low or too high), upstream/downstream passage at irrigation diversions, degraded riparian and stream habitat, and excessive temperatures in the lower river (Northwest Power Planning Council 1989).

Land-use history—The early development of the Yakima River basin followed a pattern similar to that of the Grande Ronde. Cattle and sheep grazing began in the mid-1800s, with cattle use peaking in the 1880s and sheep use peaking at the turn of the century and again during World War I. By 1907, the public had already recognized that portions of the basin were overgrazed, notably along ridgetops, which served as travel corridors, and on alluvial flats where livestock were grazed. In 1909, because of overgrazing, several drainages such as the Wenas and the Manastash, had greatly deteriorated (Cooperative Western Range Study 1938, Wissmar and others 1993). By the 1930s, sheep numbers were less than 10 percent of their historical peaks.

Before 1890, livestock grazing was concentrated on the Yakima Plateau, the surrounding foothills, and lower tributary valleys. The development of irrigation, and a subsequent boom in agriculture in the main Yakima valley forced the livestock industry to expand their summer and fall range into the tributary and headwater portion of the basin. Rapid expansion of irrigated agriculture was the turning point for economic development in the Yakima basin.

In the upper Yakima, near Cle Elum and Roslyn, coal mining and development of the Snoqualmie pass route were probably as important in altering the landscape as grazing and irrigation. The earliest timber harvest occurred along the lower slopes of the Teanaway, Menastash, Taneum, and the upper Yakima basins, from 1890 to 1900 (Plummer 1902).

Until the 1950s, timber harvest was largely limited to the harvest of large trees from the valley bottoms and adjacent hillslopes (Smith 1993), with little harvest on public lands until the 1960s. Through the 1970s this was largely limited to selective harvesting. From the mid-1970s to the present, clearcutting became a common practice, with the volume of timber harvest increasing significantly. Accompanying these practices were substantial increases in road building.

Naches River basin—The Naches River drainage is the largest tributary of the Yakima River. The upper reaches of the Naches provide summer and fall rearing habitat for more than 30 percent of the juvenile anadromous salmonids in the Yakima basin (Fast and others 1991); in addition, it contains about 60 percent of the remaining harvestable timber in the Yakima basin (U.S. Department of Agriculture, Forest Service 1990).

Little Naches River—The Little Naches River is a fifth-order basin with a drainage area of 398 km². Most of the basin lies within the Wenatchee National Forest, with portions of the upper basin under checkerboard ownership with Plum Creek Timber Co. Before 1960, land use in the Little Naches consisted of intensive livestock grazing from 1880 to 1930, small scale selective harvest in the valley bottoms, and considerable recreational use.

Before 1900, no developed roads were built in the Little Naches basin, only a few wagon trails. Until 1962, only 30 to 40 km of roads were in the basin, but between 1962 and 1990, over 450 km were constructed. Road densities in 1990 range from 1.0 to 3.1 km/km² (B. Ehinger, pers. comm.). Before 1963, timber harvest was minimal. Between 1963 and 1975, 17 percent of the available harvestable acres in the basin were cut. In 1975, clearcut harvest began in the lower basin. Clearcutting on the private checkerboard lands in the headwaters started in 1985. By 1985, 26 percent of the harvestable acres in the basin had been cut, increasing to 35 percent by 1992.

American River—The American River originates in the William O. Douglas wilderness area, along the border of Mount Rainier National Park. It flows east more than 30 km, where it meets the Naches River, draining an area of 205 km². The river is surrounded by two wilderness areas, with State Highway 410 following it for most of its course. The major effects to the American River have been caused by road construction and maintenance along with recreational development and use.

Rattlesnake Creek—Rattlesnake Creek begins in the William O. Douglas wilderness area, flowing 30 km to the east where it joins the Naches River. The upper 16 km are in the wilderness area; the lower portions of the basin are managed by the Forest Service, with some private lands near the mouth. Historically, livestock have grazed throughout the basin, with most allotments currently vacant or minimally used (J. Smith, pers. comm.). In the lower portions of the basin, timber has been harvested on both private and public land.

Upper Yakima River basin: Taneum Creek—Taneum Creek is a fifth-order tributary to the upper Yakima River, located near Thorp, Washington. The Taneum drainage extends east-southeast about 40 km to its confluence with the Yakima River. It has a drainage area of 214 km² and two major tributaries, the north and south forks.

Taneum Creek was not settled until about 1868, when several homesteads were established. Taneum Ditch was completed in 1873 to provide irrigation for the croplands along Taneum Creek and the lower Yakima Valley. Since then, the pastureland has been under continuous cultivation or grazed by livestock. Sheep were grazed along the ridgetops and riparian meadows from early summer to fall from the 1870s to the 1930s. A major sheep driveway was established up and over Cle Elum ridge into Easton.

Until the turn of the century, logging had been limited to selective cutting for homes and firewood. Shortly after the railroad arrived in 1903, Cascade Lumber Company began more intensive logging operations in the surrounding area. Several sawmills and boxmills were established along the creek, and logs were skidded out for railroad ties. A spur track of the railroad was built up the Taneum in 1928, but it was only operated through the mid-1930s. Large-scale timber harvest did not begin until the mid-1950s. By 1986, about 30 percent of the basin had been harvested, with more intensive partial and clearcut harvesting in the upper watershed since then.

Changes in fish habitat in the Yakima River basin from 1935 to 1990—The results of resurveys, conducted from 1990 to 1992, indicate that pools have increased in both managed and unmanaged portions of the Yakima River basin, with the exception of the American River, where pools decreased (table 12). These surveys also indicate that substrate composition has become coarser in the Little Naches River and Taneum Creek, but remained the same in Rattlesnake Creek (table 13). In the following sections, the results of these surveys will be examined in more detail.

Table 12. Changes in the frequency of large pools for selected managed and unmanaged streams in the Yakima River basin, 1935-36 to 1990-92.

Managed Watersheds	Kilometers Surveyed	1935-1936 #/km	1990-1992 #/km	Percent Change
Taneum Creek	17.3	0.5	3.4	580%
Little Naches River	15.6	1.7	4.6	171%
Rattlesnake Creek	8.1	1.9	4.6	142%
American River	24.5	3.3	2.4	-27%
TOTAL	65.4	1.8	3.8	111%
Unmanaged Watersheds	Kilometers Surveyed	1935-1945 #/km	1987-1992 #/km	Percent Change
Rattlesnake Creek	18.8	1.6	3.9	144%

Table 13. Changes in dominant substrate in the Yakima River Basin, 1935-36 to 1990-92.

Managed Streams	1935-1936 Dominant Substrate	1990-1992 Dominant Substrate	Change
Taneum Creek	SR (39%)	MR (43%)	+
Little Naches River	SR (37%)	LR (47%)	+
Rattlesnake Creek	LR (33%)	LR (63%)	NC
Unmanaged Streams			
Rattlesnake Creek	LR (48%)	LR (57%)	NC

Naches River basin—Three tributaries to the Naches River drainage were resurveyed from 1990 to 1992: the Little Naches and American River, along with managed and unmanaged portions of Rattlesnake Creek. The resurveys indicated that pool habitat had increased in the Little Naches and Rattlesnake Creek, but decreased in the American River (table 12).

Little Naches River—In 1990, the University of Washington began a study to examine changes in stream and riparian habitat in the Little Naches River basin (Smith 1993). The initial hypothesis, based on current observations of stream habitat, was that pool habitat had declined since the 1935 survey, but the 1990 resurvey indicated that the frequency of pool habitat had increased and that substrate composition had changed.

Anecdotal information from the 1935 survey suggests that pool habitat had already been significantly degraded by human disturbance by 1935. Although pool habitat has increased over the past 55 years, the frequency of pools is still far below any accepted standards, such as those in the Wenatchee National Forest Plan (1990) and Pacific Northwest Region, Forest Service, Standards and Guidelines (U.S. Department of Agriculture Forest Service 1991).

Pool habitat—Smith (1993) found that the frequency of large pools had increased from 1.7 to 4.6/km for the 15.6 km of stream surveyed. The increase in large pools appears to be the result of repeated scouring of the channel around areas that have been riprapped. About 80 percent of the main channel has been constrained by roads and riprap, increasing stream energy, magnifying the effects of scour at high flows, displacing smaller particles, and shifting large particles. The 1990 survey indicated that most pools were bedform scour pools controlled by large substrate and bedrock. Smith (1993) has suggested that the frequency of extreme high-flow events (40- to 100-year floods) has increased from 0.6 events/decade before 1966, to 2 events/decade after 1966. This change in peak flows coincided with increased harvest and road densities.

Substrate composition—For the Little Naches River, substrate composition changed significantly from 1935 to 1990 (table 14). In 1935, small rubble dominated the surface substrate (38 percent), with large rubble (30 percent) and medium rubble (29 percent) making up equal portions of the bottom. Both fine sediment (1.0 percent) and bedrock (2.0 percent) were small portions of the surface substrate. By 1990, the channel surface had coarsened and small rubble was replaced by large rubble. Large rubble dominates surface substrate (47 percent) with small rubble decreasing to 15 percent. Minor increases in fine sediment and bedrock also occurred but medium rubble stayed the same.

Table 14. Substrate composition of the Little Naches River in 1935 and 1990.		
Substrate Class	1935 mean (%)	1990 mean (%)
Large Rubble (LR)	30.0	47.0
Medium Rubble (MR)	29.0	28.0
Small Rubble (SR)	38.0	15.0
Mud and Sand (MS)	1.0	6.0
Bedrock (BR)	2.0	4.0

The increase in percent fines (MS) in the Little Naches, along with the high degree of embeddedness, suggests that the input of fine sediment has increased since 1935. At the same time, large rubble has increased significantly, now comprising almost 50 percent of the surface substrate. Large rubble can be an important component of rearing habitat if it is not embedded. Juvenile fish use the interstitial spaces for thermal cover in winter and hiding cover in summer (Bjornn and Reiser 1991). Aquatic insects also use interstitial spaces, providing a food source for fish.

Large woody debris—Comparisons of the frequency of large woody debris from aerial photographs (1962 and 1990) indicate a lack of wood in the lower reaches of the Little Naches. Although large woody debris increased from 1962 to 1990, the frequency still remains far below the Forest Plan standard of 62 pieces/km (U.S. Department of Agriculture, Forest Service 1990). The upper reaches have twice the frequency of the lower reaches, but little of this wood was associated with pools; most of the wood was in a few debris jams. Even though the association of large woody debris with pool habitat was weak, the increased may contribute to pool formation and increased habitat complexity in the future.

Conclusion—The historical survey indicates that pool habitat was not abundant in the 1935 survey. Although pools had increased by 1990, the frequency of pool habitat was still below current standards. With most of the mainstem now constrained by roads and riprap, the potential of the stream to create pool habitat may be severely reduced, especially in the lower reaches. Constrained channels typically have more high-gradient habitats, such as riffles, rapids, and cascades (Grant 1986), except at meander bends where large pools may form and persist (Lisle 1986). Current standards may need to be revised for streams of this nature, and efforts at rehabilitation may need to be rethought.

For example, alternative types of rearing habitat may need to be considered for restoration efforts. Side-channel areas that were cutoff from the main channel through road construction could be reconnected to provide highly productive refuge areas. Also, instead of trying to create large pools from riffle areas, riffle areas can be made more complex. Pocket pools and step-pool cascades can be established in riffles with large and small boulders combined with large woody debris. Besides providing cover, these structures lower stream energy and reduce the scour and erosive power that removes the structural components.

Even though pools increased over time, other habitat components critical to abundant and high quality spawning and rearing habitat have been reduced over the last 55 years. Off-channel habitat, channel complexity, riparian cover, and spawning gravels all have decreased over time. In addition, substrate embeddedness, percentage of fines, and water temperatures are above currently accepted values for fish.

Rattlesnake Creek—Our resurvey results indicated that pool habitat increased in both the managed and unmanaged portions of the basin by the same magnitude (table 12). Current pool frequencies remain quite low compared to current standards. A possible explanation for the improving trend may be recovery from intensive grazing in the early part of the century, followed by wilderness protection for the headwaters, and relatively little management activities in the lower portions (J. Smith, pers. comm.). No changes were observed in dominant substrate in either the managed or unmanaged portions of the basin (table 13).

American River—Survey results indicated that pool habitat has decreased by over 25 percent (table 12), with pools becoming shallower. The river has been altered over time by the continuous maintenance and realignment of the highway, along with heavy recreational use along the limited floodplain. These activities are likely to have influenced pool habitat by increased sediment loads which could result in the filling of pools (J. Smith, pers. comm.). In addition, debris removal for road and bridge maintenance is likely to have reduced channel complexity (for example, large woody debris), further reducing pool habitat. Road construction and maintenance, along with recreational development, have probably provided chronic and persistent sediment sources.

Upper Yakima River: Taneum Creek pool habitat—The frequency of large pools increased from 0.5/km to 3.4/km from 1936 to 1990 in Taneum Creek (table 12). Although the frequency of pools increased seven-fold, current frequencies are quite low for a stream of this size, indicating a general lack of pool habitat.

Substrate composition—In 1936, substrate was dominated by small and medium rubble (40 and 39 percent overall, table 15). By 1990, medium rubble (43 percent) was the dominant substrate, with a subsequent decrease in small rubble (26 percent) and increase in fine sediments (18 percent). The current level of fine sediments is approaching Forest Plan standards (< 20 percent fines). Furthermore, the most upstream reach exceeds the forest standard by 5 percent. The increase in percentage of fines, along with the embedded condition of the bed throughout most reaches, indicates that fine sediments have increased over the past 50 years. The ability of the stream to export fines has been exceeded.

Table 15. Substrate composition of Taneum Creek in 1935 and 1990.

Substrate Class	1935 mean (%)	1990 mean (%)
Large Rubble (LR)	14.0	13.0
Medium Rubble (MR)	39.0	43.0
Small Rubble (SR)	40.0	26.0
Mud and Sand (MS)	7.0	18.0
Bedrock (BR)	0.0	0.0

Conclusion—The historical record indicates that grazing pressure had greatly diminished in Taneum Creek by the 1930s. From that period until the 1970s, land-use effects were largely limited to agriculture in the lower reaches, with some selective timber harvest along the mainstem of the creek. This period of relative inactivity may have provided a window over which stream habitat began to show some recovery from past effects. From the 1970s to the present, the basin has experienced greatly accelerated road construction and timber harvest.

The effects of intensive logging over the past 20 years are likely to curtail further recovery in pool habitat, as evidenced by increased fine sediments and high embeddedness, and may result in further declines in habitat conditions in the future. With accelerated harvest in the steep headwaters areas, along with chronic surface erosion from sparsely vegetated upland meadows, fine sediments are likely to persist for some time. This condition may result in decreased pool habitat through sedimentation, accompanied by a reduction in fish productivity from the direct effects of fine sediments on salmonid reproduction.

Summary—Recent research (Mullan and others 1992, Wissmar and others 1993, this volume) indicates that the land-use history in the mid-Columbia region may be quite different from patterns seen west of the Cascades and in the Snake River basin, thus influencing the effects to riverine ecosystems. Generally, streams were heavily affected by livestock grazing from about 1860 to 1920. After that point, development pressures were concentrated in the larger river valleys, while the headwater and tributary portions of the basins had a period of relative inactivity. This pattern changed in the late 1950s, as timber harvest and road construction began in the upper portions of the basins. Harvest practices changed over time from selective harvest to clearcutting. Since the 1970s, timber harvest has accelerated dramatically throughout the mid-Columbia region (Wissmar and others 1993).

The period of relative inactivity in the tributary portions of the Yakima basin, followed by much later entry for timber harvest, may explain the trend in increased pool habitat. These trends must be viewed in the perspective of current standards for pool habitat. None of the streams we have surveyed meet current Forest Service standards for pool habitat (table 4). Although the trend in improving habitat is encouraging, the stream habitats we surveyed are still in poor condition. Given the late entry for timber harvest, stream habitats may not be expressing the full cumulative effects of harvest activities. Management priorities for stream protection should emphasize continuing these improving trends.

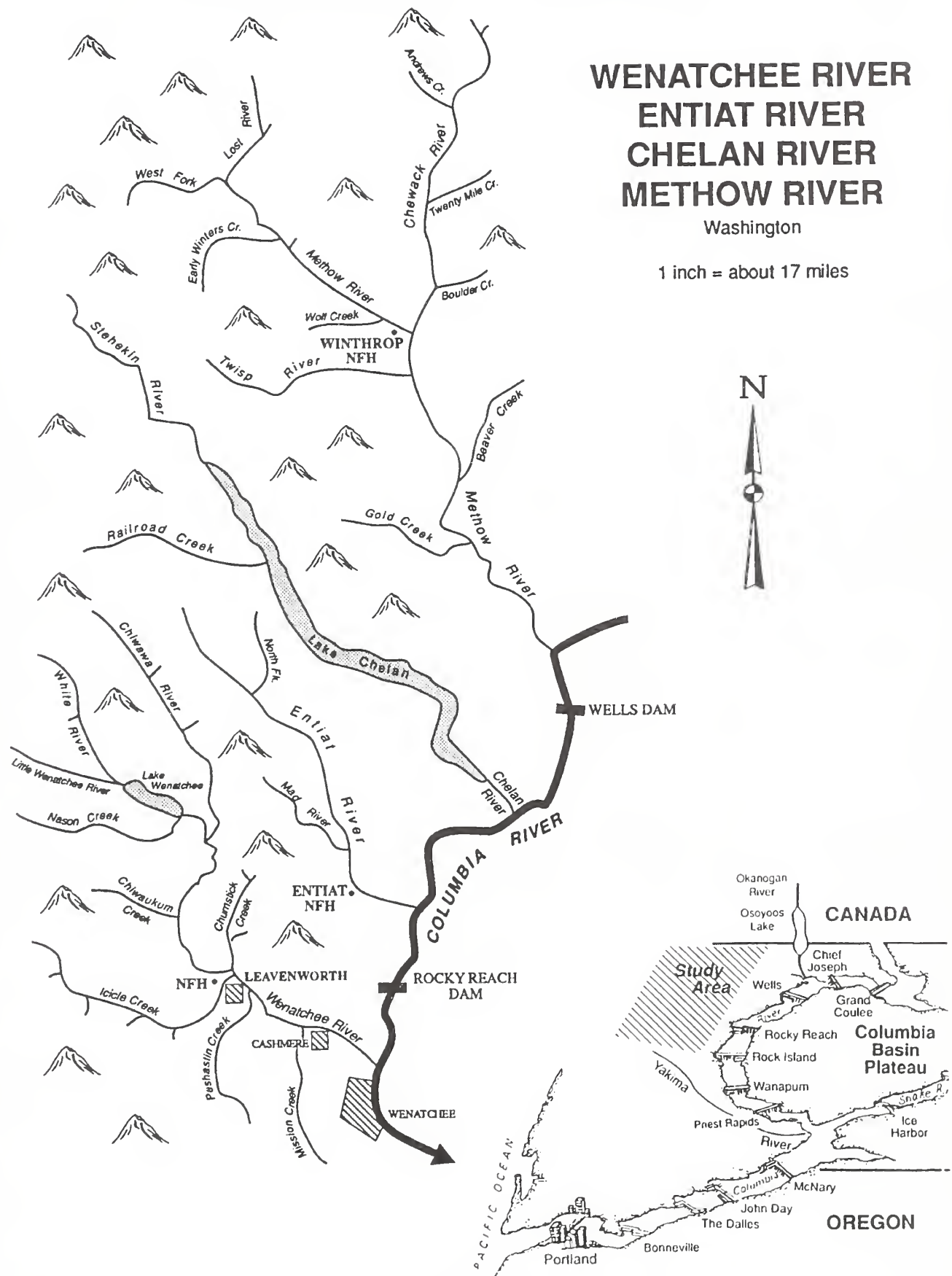


Figure 17. Wenatchee and Methow River basins, Washington

Changes in Fish Habitat—Wenatchee River Basin, Washington

Study area—The Wenatchee River basin is located in north-central Washington, draining an area of 3437 km² (fig. 17). It flows to the southeast from glacial outflow in the Cascade Range, through mountainous, heavily forested reaches, to a broader, more arid valley at its confluence with the Columbia. The basin's climate is strongly influenced by the orographic effects of the Cascades; the region is in the coldest of 24 western climate zones (Mullan and others 1992). Precipitation is primarily winter snowpack, with little falling from April to September.

Irrigated agriculture, primarily fruit orchards along the lower river, has been the economic base of the Wenatchee basin. Livestock production and forestry are also important components of the economy. The basin is about 80 percent public land, mostly in the mountainous, forested regions.

Historically, the Wenatchee had large runs of spring/summer/fall chinook, coho salmon, sockeye salmon, and steelhead. Coho runs were probably a minor component of the population, and these small runs became extinct sometime after the 1940s. Recent research (Mullan and others 1992) suggests that current wild runs appear to be similar in size to historical runs (table 16). Although total run sizes are about the same, the species composition of the runs has shifted substantially—coho are extinct and sockeye reduced. The majority of the run is now spring chinook. Summer steelhead were listed as a species of special concern by Nehlsen and others (1991), primarily because of the effects of hatchery introgression.

Table 16. Historical and current run sizes of naturally produced salmon and steelhead in the Wenatchee River basin (from Mullan and others 1992).

Species	1850s	1967-87
Chinook Salmon	41,300	204,800
Coho Salmon	3,900	0
Sockeye Salmon	228,100	93,700
Steelhead	7,300	8,200 [a]
TOTAL	280,600	306,700

[a] - for years 1987-1989.

Land use history—The historical pattern of land use in the Wenatchee basin follows a familiar pattern in the Pacific Northwest. Mining was probably the first activity during the settlement era, beginning in the 1870s. The records indicate that mineral production was minor, with effects being mostly local and short lived (Mullan and others 1992, Wissmar and others 1993).

After the advent of mining was a period of intense livestock grazing, similar to what has been documented for other river basins. Grazing pressure was highest from the late 1800s to the 1930s, with subsequent reductions as allotment systems replaced the open range (Carter 1990). Currently, the Wenatchee National Forest lists no rangelands in unsatisfactory condition, with most considered to be improving (U.S. Department of Agriculture, Forest Service 1990).

As with the Yakima basin, timber harvest came later to the Wenatchee. Up until 1955, selective harvest or "high grading" was the primary harvest method. Since then, partial cutting and clearcutting have been the predominant practices. The 1980s represent the period of most intense harvest (Mullan 1992, U.S. Department of Agriculture, Forest Service 1990). Even with increased harvest in the past decade, about 65 percent of the Wenatchee National Forest is currently designated as wilderness or roadless areas (U.S. Department of Agriculture, Forest Service 1990).

Although the basin has been affected by stream channelization, irrigation, and pollution, these effects are not nearly as extensive as those found in the Yakima basin. A major effect early in the century were dams and irrigation diversions with inadequate bypass or screening facilities. Overfishing by Euro-Americans was also a problem during the settlement period.

Fires have been an important part of the natural disturbance regime in the Wenatchee River basin. Variations in the pattern, magnitude, and frequency of fire are complex throughout the Wenatchee. In the presettlement era, Native Americans used fire to maintain and enhance their hunting and berry producing areas (Mullan and others 1992). With the initiation of fire suppression, fuels have accumulated and vegetative composition has changed, from open stands of fire-tolerant species to dense stands of less fire-tolerant species. These changes have increased fire frequencies, and the risk of catastrophic fires are much greater.

Changes in fish habitat in the Wenatchee River basin from 1935 to 1991: pool habitat—

During 1991, the Pacific Northwest Research Station surveyed four streams in the Wenatchee River basin, covering more than 70 km of streams. Three of the streams were in unmanaged basins, and one was in a managed watershed. Pool habitat increased in both the managed and unmanaged portions of the basin (table 17), with both having similar pool frequencies in the resurveys. Compared to Nason Creek, which is the stream in the managed area, the increase was twice as great in the unmanaged portions of the basin.

Table 17. Change in the frequency of large pools for selected streams in the Wenatchee River Basin, 1935-37 to 1991.

Managed Watersheds	Kilometers Surveyed	1935-1937 #/km	1991 #/km	Percent Change
Nason Creek	33.6	4.9	7.7	57%
Unmanaged Watersheds	Kilometers Surveyed	1935-1945 #/km	1987-1992 #/km	Percent Change
Jack Creek	6.8	1.9	8.1	326%
Icicle Creek	14.1	3.8	10.3	171%
Chiwawa River	59.1	1.8	4.2	133%
TOTAL	80.0	2.5	7.5	200%

The reasons for the increases in pool habitat are largely unknown at this point, but several explanations are possible. We know that the Wenatchee has had several large flood events (return interval 40 to 100 years) since the surveys in the 1930s; the most recent was in 1990. Our 1991 surveys indicated that the 1990 flood was probably a major pool-forming event in the Wenatchee systems. In some systems, such as the Chiwawa River, evidence of debris flows, which brought large woody debris and boulders to the stream channel, was extensive. In addition, the interaction of the flood with the Chiwawa's large, intact riparian floodplain greatly increased channel complexity.

A contrast to this would be Nason Creek, which has an extensive management history. In the lower portions, Nason Creek has a fairly broad floodplain that has been significantly altered and constrained by a railroad grade and a State highway. The historical record indicates that timber resources had been significantly reduced by the turn of the century, because of the demands of the railroad (Plummer 1902). In addition, the railroad right-of-way has been burned repeatedly to maintain passage, which undoubtedly had a large effect on riparian vegetation (Mullan and others 1992). Although Nason Creek showed an increase in pool habitat from the 1930s survey, the increase was considerably less than what we found in the unmanaged systems. This finding suggests that unmanaged systems with intact, fully functional floodplains, were further enhanced by the interaction with large flood events, which are a key to shaping and maintaining high-quality fish habitat.

Substrate composition—Changes in dominant substrate varied for surveyed streams in the Wenatchee River basin (table 18). Of the unmanaged streams, two did not change, and Icicle Creek shifted to a finer dominant substrate. Nason Creek, the managed stream, also had a shift to finer substrate.

Table 18. Changes in dominant substrate in the Wenatchee River basin, 1935-36 to 1991.			
Managed Streams	1935-1936 Dominant Substrate	1991 Dominant Substrate	Change
Nason Creek	LR (33%)	MR (34%)	--
Unmanaged Streams			
Jack Creek	LR (76%)	LR (45%)	NC
Icicle Creek	LR (48%)	SR (26%)	--
Chiwawa River	LR (46%)	LR (33%)	NC
MR = medium rubble, SR = small rubble, NC = no change, - = decrease			

Large woody debris—As the general trends for eastside river basins have indicated, large woody debris is much more prevalent in unmanaged than in managed streams in the Wenatchee River basin (table 19). From the unmanaged (72.5 pieces/km) to the managed streams (26.7 pieces/km) there was nearly a three-fold increase in large woody debris. Also, the frequency of large woody debris complexes was much higher in the unmanaged streams. As an example, the Chiwawa River has a very complex stream channel, with numerous debris jams and multiple channels throughout its course and is representative of the potential of these systems to create highly diverse stream habitat.

Table 19. Current amounts of large woody debris (LWD > 0.1 m diameter and > 2.0 m length) in selected managed and unmanaged streams in the Wenatchee River basin.			
Managed Streams Name	LENGTH (KM)	LWD (#/KM)	LWD COMPLEXES (#/KM)
Nason Creek	33.6	26.7	3.5
Unmanaged Streams Name	LENGTH (KM)	LWD (#/KM)	LWD COMPLEXES (#/KM)
Jack Creek	6.8	73.3	10.7
Icicle Creek	14.1	81.9	11.2
Chiwawa River	59.1	62.4	13.9
TOTAL	80.0	MEAN 72.5	11.9

Summary—The historical resurveys, along with Mullan and others (1992), indicate that fish habitat is in good condition in the Wenatchee River basin. The primary effects to anadromous salmonids appear to be irrigation diversions and low flows in the mainstem Wenatchee River. Some tributaries, such as Mission Creek, are in poor condition, but they represent a small portion of the total habitat.

The data from this case history strongly imply that the stability of anadromous fish runs in the Wenatchee River basin are tied to the abundance of high-quality habitat. This condition is largely because most of the Wenatchee National Forest is in wilderness or roadless designation. Having a wealth of intact headwater and floodplain areas has helped shape and maintain productive fish habitat. To maintain the productivity of the Wenatchee River basin, these features of the landscape must be maintained.

Changes in Fish Habitat—Methow River Basin, Washington

We resurveyed 176 km of streams in the Methow River basin during the summer of 1992, including most of the mainstem Methow, along with the two major drainages, the Chewack and Twisp Rivers. The survey results indicated that the frequency of large pools had increased significantly in both managed and unmanaged systems over the past 50 years.

Summary documents from the historical survey indicate that pools were infrequent at the time of the survey, with no suggestion as to a cause. Although current pool frequencies have more than doubled, the cause is not obvious. Whether the reason is natural geomorphic constraints or is an artifact of past disturbance, natural or human, is unknown. Using the historical record, we will examine potential reasons for the improvement in pool habitat.

Study area—The Methow River basin is in north-central Washington, just south of the Canadian border (fig. 17). It drains an area of 4641 km² as it flows about 140 km from the crest of the Cascades to the Columbia River. About 80 percent of the basin is public land managed by the Forest Service, with the lower 100 km of the river in private ownership. Logging and livestock production are the economic base of this sparsely populated basin, with orchards also a significant part of the local economy.

The basin is characterized by a wide alluvial valley and forested uplands. Glaciers have provided extensive alluvium throughout the valley, often several hundred meters deep, which has allowed for development of significant groundwater storage in the floodplain (Wissmar and others 1993). Many reaches of streams in the upper basin naturally de-water during periods of low flow because of this. Like the Wenatchee, the Methow is located in the coldest of 24 western climate zones (Mullan and others 1992).

Before settlement by Euro-Americans, the Methow supported significant runs of spring/summer chinook salmon, coho salmon, and steelhead, with coho being the most abundant (Mullan and others 1992, table 20). By 1941, coho were at or near extinction because of impassable dams, unscreened irrigation diversions, overharvest, and the indiscriminate use of coho eggs for early hatchery programs. Currently, anadromous salmonid stocks are supported by chinook salmon and steelhead in the Methow. Recent research suggests that current runs exceed the historical runs in the Methow River basin, with chinook replacing coho (Mullan and others 1992). Wild steelhead were listed as having a high risk of extinction by Nehlsen and others (1991), primarily because of the effects of irrigation and hatchery introgression.

Table 20. Historical and current run sizes of naturally produced salmon and steelhead in the Methow River basin (from Mullan and others 1992).

Species	1850s	1967-87
Chinook Salmon	24,200	86,100
Coho Salmon	36,000	0
Steelhead	3,600	5,000 [a]
TOTAL	63,800	91,100
[a] - for years 1987-1989		

Land use history—The land-use history of the Methow River basin is similar to the other river basins of central Washington. Unlike the other basins, though, the Methow remains very sparsely populated. The first settlers in the basin were miners and livestock grazers. With its extensive floodplain and gentle uplands, the Methow provided excellent summer range for livestock. The heyday of grazing was from the late 1800s, continuing until after the turn of the century, with subsequent declines. As with the other river basins in the Pacific Northwest, sheep grazing came first, followed by cattle grazing. Undoubtedly, stream and riparian habitats suffered under this intensive grazing pressure, providing a legacy that continues today in many places.

As the basin was settled, fruit orchards became prominent on terraces throughout the floodplain, although not as extensively as in the Wenatchee. To support a growing fruit business, extensive irrigation was developed throughout the lower reaches of the Methow. As noted previously, dams and irrigation diversions greatly contributed to the decline of anadromous salmonids in the Methow early in the century.

Timber harvest and road construction of any significance began in the 1970s in the Methow (J. Spotts, pers. comm.). The current Forest Plan (1989) indicates that about 75 percent of the forest is designated as wilderness or roadless areas. Before the 1970s, timber harvest was limited to the riparian zone and adjacent hillslopes. The Twisp basin has had the most management activities over the development period (J. Spotts, pers. comm.).

Changes in fish habitat in the Methow River basin from 1935 to 1992: pool habitat—During the summer of 1992, the Pacific Northwest Research Station resurveyed the three major drainages of the Methow River basin, namely the Chewack and Twisp Rivers, along with the upper 70 km of the Methow River. Our surveys indicated that pool frequencies doubled in the managed portions of the basin, and increased more than three-fold in the unmanaged portion (table 21).

Table 21. Change in the frequency of large pools for selected streams in the Methow River basin, 1935-37 to 1991.

Managed Watersheds	Kilometers Surveyed	1935-1937 #/km	1991 #/km	Percent Change
Chewack River	33.9	1.0	3.5	250%
Methow River	69.6	1.4	3.0	114%
Twisp River	42.5	2.8	3.9	37%
TOTAL	146.0	1.7	3.4	100%
Unmanaged Watersheds	Kilometers Surveyed	1935-1945 #/km	1987-1992 #/km	Percent Change
Chewack River	30.3	1.0	3.4	40%

The low pool frequencies indicated by the 1930s survey suggest that stream habitat was in poor condition at the time. The period of declining grazing coupled with late entry for timber harvest may have allowed some time for stream habitat to recover. The important point is not the size of the change, but the direction. Both the Chewack and the Methow are near current Forest Service standards for large pools, with the Twisp still below them.

Substrate composition—Comparisons of substrate composition in the Methow River basin indicated no significant trends (table 22). The exception was the Methow River, where the dominant substrate shifted from medium rubble to small rubble.

Table 22. Changes in dominant substrate in the Methow River basin, 1934-38 to 1992.

Managed Streams	1934-1938 Dominant Substrate	1992 Dominant Substrate	Change
Methow River	MR (44%)	SR (39%)	--
Twisp River	MR (35%)	MR (33%)	NC
Chewack River	MR (34%)	MR (35%)	NC
Chewack River (unmanaged)	LR (35%)	LR (49%)	NC

MR = medium rubble, SR = small rubble, NC = no change, - = decrease

Large woody debris—The frequency of large woody debris in the Methow basin was the reverse of what was detected in the other river basins (table 23). About 50 percent more large woody debris and debris complexes were found in the managed portions of the basin than in the unmanaged portion. This distribution may be an anomaly, the result of a large fire in the headwaters of the Chewack River in 1929, described below. The apparent high-intensity of this fire may have eliminated much of the large woody debris and set back future recruitment, which later became evident in the current survey.

Table 23. Current levels of large woody debris (LWD > 0.1 m diameter and > 2.0 m length) in selected managed and unmanaged streams of eastern Oregon and Washington.

Managed Streams Names	LENGTH (KM)	LWD (#/KM)	LWD COMPLEXES #/KM
CHEWACK RIVER	33.9	71.5	12.5
METHOW RIVER	69.6	50.6	7.8
TWISP RIVER	42.5	85.6	16.7
TOTAL	146.0	MEAN 69.2	12.3
Unmanaged Streams Name	LENGTH (KM)	LWD (#/KM)	LWD COMPLEXES #/KM
CHEWACK RIVER	30.3	40.2	8.1

Summary—As examples of different disturbance regimes and how these systems have changed over the past 50 years, we will examine the Twisp and Chewack Rivers. When the Chewack was surveyed in 1935, the surveyors noted that:

the hillsides are covered by a good growth in the lower and upper reaches with the exception of the last three miles of stream surveyed. This area was burnt over by a fire in 1929 which killed the timber and killed the underbrush. At the time of the survey, there was [sic] little or no protected stretches along the stream banks.

Based on this description, the low frequency of pools in 1935 is likely explained by the effects of the 1929 fire. Also, this portion of the basin has not been affected by human activities and is currently a wilderness area, thus raising the likelihood of this explanation.

In contrast, the Twisp river has been a managed river basin since settlement. At the time of the 1935 survey, extensive irrigation development to support fruit orchards was noted in the lower 20 km of the river. The upper portions of the basin had been grazed, but no extensive burns were reported. In the historical survey, the Twisp River had a pool frequency three times greater than the Chewack—most likely explained by its relatively undisturbed state as compared to the Chewack, which had experienced the 1929 fire. Since 1935, the Twisp has had the most intensive timber harvest of all the drainages in the Methow River basin (J. Spotts, pers. comm.). The management history of the Twisp may explain why it shows the least improvement in pool habitat of the streams resurveyed.

IDENTIFICATION OF KEY WATERSHEDS WITH HIGH-QUALITY FISH HABITAT AND THOSE WITH THE GREATEST POTENTIAL FOR RESTORATION

Fishery and aquatic specialists generally recognize that conservation and restoration efforts for aquatic resources need to be focused at the watershed scale (Johnson and others 1991, Meehan 1991, Reeves and Sedell 1992, Sheldon 1988, Williams and others 1989, Wissmar and others 1993). This section identifies key watersheds in eastern Oregon and Washington that can serve as cornerstones to regional protection and restoration efforts for aquatic systems (table 24a, b; figs. 18, 19).

The criteria for selection were based on Johnson and others (1991) and Reeves and Sedell (1992). Key watersheds were larger than 15 km² and contained relatively high-quality water and fish habitat, or had the potential to provide high-quality habitat with appropriate restoration efforts; and contained habitat for threatened or potentially threatened anadromous and resident fish species. These watersheds were determined by Federal, State, and Tribal fish biologists from across the region.

Table 24a. List of key watersheds for anadromous and resident fish in Washington.

Forest/Watershed	Steelhead/		Coho	Chinook				Sea run cutthroat trout	Bull trout	West slope cutthroat trout	Other
	Sum	Win		Spr	Sum	Fall	Win				
OKANOGAN NF											
COLUMBIA R.											
METHOW R.											
20 Twisp R.	X			P	X						C2
21 Early Winters Cr.	X			P					X		C2
21 Upper Methow R.	X			P					X		C2
22 Chewack R. [1]	X			P							
WENATCHEE NF											
COLUMBIA R.											
YAKIMA R.											
11 Teiton R.									X		
12 Rattlesnake Cr.	P			P					X		
13 Bumping American R.				P					X		
14 Cle Elum R.									X		P(9)
WENATCHEE NF											
15 Ingalls Cr.	X								X		C2
16 Mission Cr.	X										C2
17 Icicle Cr.									X		C1,C2
18 Upper Wenatchee R. [2]	X			P					X		P(9)
19 Entiat. R.	X			P					X		

Table 24b. List of key watersheds for anadromous and resident fish in eastern Oregon.

Forest/Watershed	Steelhead/ Trout		Coho	Chinook				Sea run cutthroat trout	Bull trout	West slope cutthroat trout	Other
	Sum	Win		Spr	Sum	Fall	Win				
<u>WINEMA NF</u>											
KLAMATH R.											
19 Clover Cr.											C2
20 Rainbow Cr.											C2
21 Pelican Butte											C1,C2
22 Cherry Cr.									X		
23 Seven Mile Cr.									X		
24 Evening Cr.									X		
<u>DESCHUTES NF</u>											
COLUMBIA R.											
DESCHUTES R.											
52 Big Marsh Cr.									X		
53 Odell Cr.									X		C2
54 Deschutes R. Corridor, Lava Lake to Crane Prairie [1]									X		C2
55 Cultus Cr.											C2
56 Deschutes R. Corridor, Dilman Meadows to La Pine Rec. Area [1]											C2
57 Deschutes R. Corridor, Benhan Falls Camp to Dillon Falls [1]											C2
58 Tumalo Cr.											C2
59 Squaw Cr.											C2
61 Metolius R.									X		C2
60 Three Creeks Meadows & Creek [1]											C2
<u>MT. HOOD NF</u>											
COLUMBIA R.											
DESCHUTES R.											
69 White R. [3]	P										X(5),C2
70 Fifteen Mile Cr./Ramsey Cr.	X	X									
72 W. Fork Hood R.	X	X	X	X				X			
67 Eagle Cr.		P	P	P							C2
71 Mill Cr./Five Mile Cr./Eight Mile Cr.		X									C2

Table 24b. List of key watersheds for anadromous and resident fish in eastern Oregon (continued).

Forest/Watershed	Steelhead/ Trout		Coho	Chinook				Sea run cutthroat trout	Bull trout	West slope cutthroat trout	Other
	Sum	Win		Spr	Sum	Fall	Win				
<u>OCHOCO NF</u>											
COLUMBIA R.											
JOHN DAY R.											
73 Rock Cr.	P										X(5)
74 Black Canyon Cr.	P										X(5)
75 Cottonwood Cr.	P										X(5)
DESCHUTES R.											
76 Trout Cr.	P										X(5)
<u>MALHEUR NF</u>											
COLUMBIA R.											
JOHN DAY R.											
77 Fields Cr.	P									P	
CANYON CR.											
78 E. Fork Canyon Cr.	P									P	
79 M. Fork Canyon Cr./Canyon Cr.	P									P	
80 Reynolds Cr./Deardorf Cr.	P			X					X	P	
John Day R. Headwaters											
MIDDLE FORK JOHN DAY R.											
81 M. Fork John Day R. Corridor, Galena to Phipps Meadow [1]	P			X							
83 Camp Cr.	P			X					X		
84 Big Boulder Cr.	P			X					X		
84 Granite Boulder Cr.	P			X					X		
84 Beaver Cr./Little Boulder Cr./Caribou Cr./Vincent Cr./Vinegar Cr.	P										
85 Davis Cr.	P								X		
86 Clear Cr.	P			X					X		
82 Big Cr.	P			X					X	P	
SOUTH FORK JOHN DAY R.											
87 Murderers Cr.	P										

Table 24b. List of key watersheds for anadromous and resident fish in eastern Oregon (continued).

Forest/Watershed	Steelhead/ Trout		Coho	Chinook				Sea run cutthroat trout	Bull trout	West slope cutthroat trout	Other
	Sum	Win		Spr	Sum	Fall	Win				
<u>WALLOWA-WHITMAN NF</u>											
COLUMBIA R.											
JOHN DAY R.											
N. FORK JOHN DAY R.											
88A Upper N. Fork John Day R.	P			X					X		
89A Granite Cr./Bull Run Cr./Beaver Cr.	P			X					X		
SNAKE R.											
GRANDE RONDE R.											
90 Meadow Cr.	P										
91 Beaver Cr.	P										
92 Upper Grand Ronde R.	P			X					X		
93 Upper Catherine Cr.	P			X							
94 Minam R.	P			X					X		
95 Wallowa R./Lostine R.	P			X							
96 Joseph Cr.	P										X(5)
96 Cottonwood Cr.											X(5)
97 Imnaha R.	X			X		X			X		
98 Cherry Cr.											X(5)
<u>UMATILLA NF</u>											
COLUMBIA R.											
JOHN DAY R.											
88B Upper N. Fork John Day R.	P			X					X		C2
89B Granite Cr.	P			X							C2
89B Clear Cr.	P			X							
99 Desolation Cr.	P			X					X		C2
100 Camas Cr.	P										
101 Fivemile Cr.	P										
102 Potamus Cr.	P										C2
103 Wall Cr.	P										

Table 24b. List of key watersheds for anadromous and resident fish in eastern Oregon (continued).

Forest/Watershed	Steelhead/ Trout		Coho	Chinook				Sea run cutthroat trout	Bull trout	West slope cutthroat trout	Other
	Sum	Win		Spr	Sum	Fall	Win				
SNAKE R.											
GRAND RONDE R.											
104 Looking Glass Cr.	P			X					X		C2
105 Wenaha R. [4]	P			X					X		C2
106 Wenatchee Cr. [4]	X			X					X		C2
107 Asotin Cr. [4]	X			X					X		
108 Tucannon R. [4]	X			X					X		
WALLA WALLA R.											
109 N. Fork Walla Walla R.	X								X		C2
110 S. Fork Walla Walla R.	X								X		C2
111 Touchet R. [4]	X								X		
112 Umatilla R.	P								X		C2

P Present in streams of watershed

X Identified as at risk or declining by the Endangered Fish Committee of the American Fisheries Society

C1 High-Quality water source

C2 Unique or high-value resident trout populations

5	Red-band trout	Spr	Spring race
6	Chum salmon	Sum	Summer race
7	Oregon chub	Fal	Fall race
8	Pink salmon	Win	Winter race
9	Sockeye salmon		
10	Olympic mudminnow		

Common name

Chinook salmon
Coho salmon
Steelhead trout
Sea-run cutthroat trout
West-slope cutthroat trout
Sockeye salmon
Chum salmon
Pink salmon
Red-band trout
Bull trout
Oregon chub
Olympic mudminnow

Scientific name

Oncorhynchus tshawytscha
O. kisutch
O. mykiss
O. clarki clarki
O. clarki lewisi
O. nerka
O. keta
O. gorbuscha
O. mykiss gibbsi
Salvelinus confluentus
Oregonichthys crmeri
Novumbra hubbsi

[1] 1/4 mile no-harvest area on each side of stream.

[2] Includes Wenatchee R., White R., Nepeequa R., and Chiwawa R.

[3] Includes Rock Cr., badger Cr., Tygh Cr., and Jordan Cr.

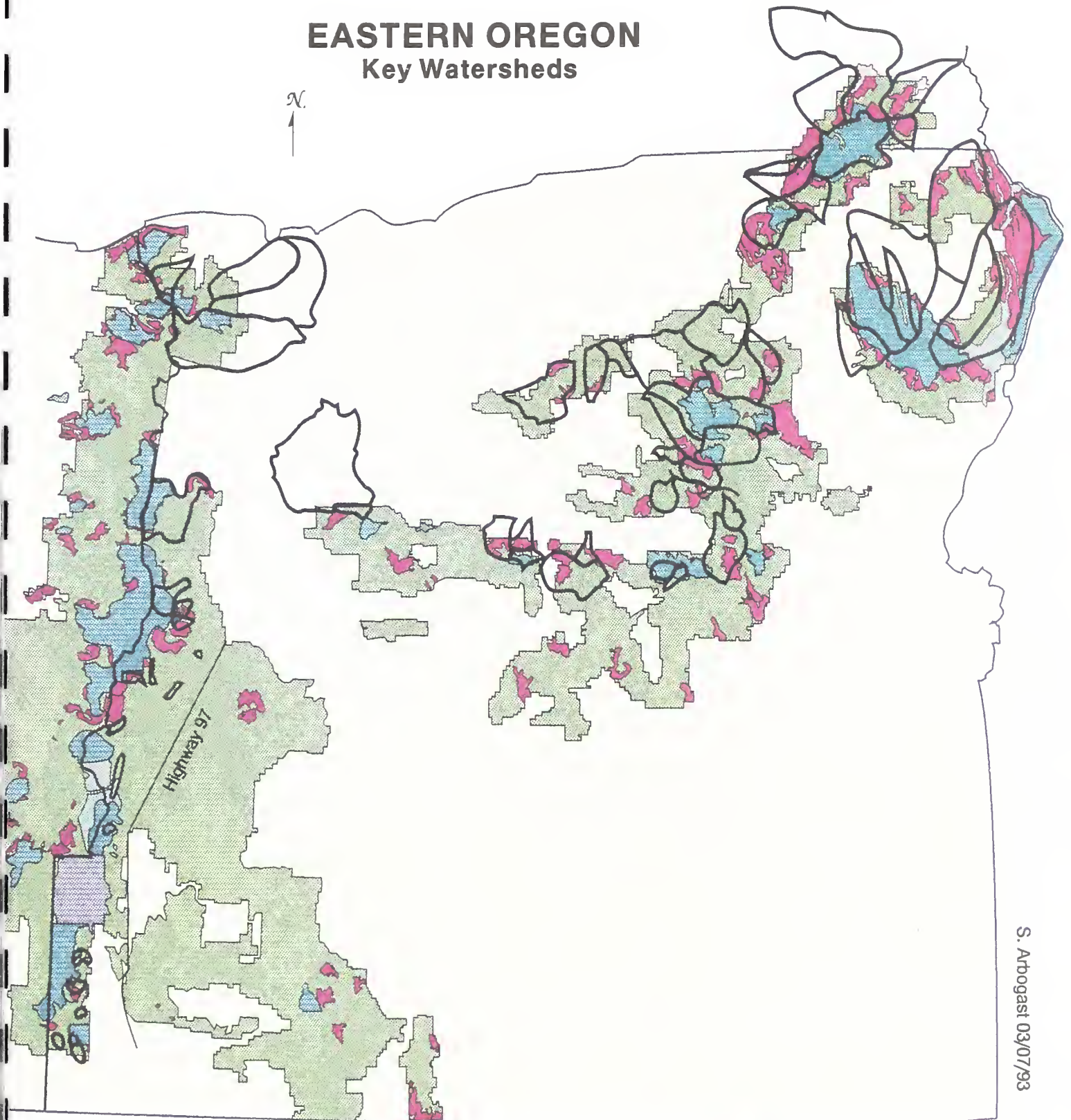
[4] Administered by Umatilla NF (Oregon), but located in Washington.

Figure 18 (next page). Key watersheds for eastern Oregon.

Figure 19 (following page). Key watersheds for eastern Washington.

EASTERN OREGON

Key Watersheds

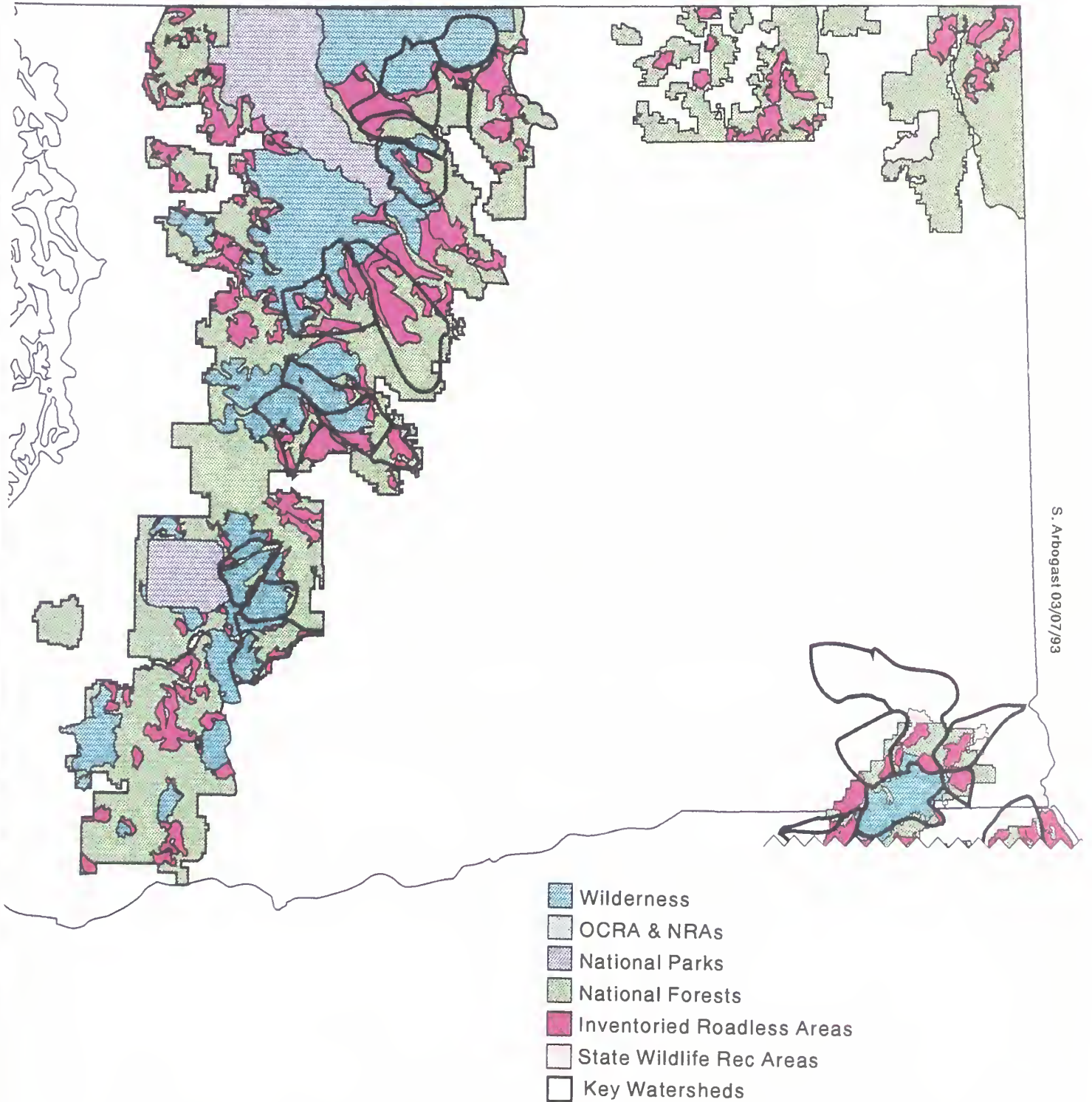


-  Wilderness
-  OCRA & NRAs
-  National Parks
-  National Forests
-  Inventoried Roadless Areas
-  State Wildlife Rec Areas
-  Key Watersheds

S. Arbogast 03/07/93

EASTERN WASHINGTON

Key Watersheds



S. Arbogast 03/07/93

DISCUSSION

In this paper, we have examined how fish habitat has changed in select river basins of eastern Oregon and Washington over the past 50 years. These snapshots over time show considerable variability in how fish habitats have been affected by natural and human-induced disturbance. Although quantifiable relations between land-use practices and long-term trends in fish abundance have been difficult to obtain (Bisson and others 1992), the body of literature concludes that land-use practices have simplified fish habitat (Bisson and others 1992, Hicks and others 1991, Meehan 1991).

"Simplification" means a loss in the frequency and diversity of habitat types—pools, riffles, side-channels—decreased large woody debris and other structural elements, and declining water quality (higher temperatures) (Reeves and Sedell 1993). Although the general trend throughout the Columbia River basin has been towards a loss in pool habitat on managed lands and stable or improving conditions on unmanaged lands, the data also suggest a regional pattern to this change.

The river basins of eastern Washington apparently had a period of recovery after World War I, which may have allowed stream habitat to show moderate improvement since then. In contrast, the river basins of eastern Oregon have been affected continuously over the entire settlement period (1850-1930), explaining their current degraded state. The cumulative effects of these impacts have operated collectively, exacerbating or magnifying the effect of any one factor operating in isolation.

Our analysis of changes in fish habitat and the chronology of settlement and land use suggests a different response for each basin because of the timing and duration of human disturbance events, acting individually and synergistically. The historical records indicate that during the settlement era, the major influence on stream ecosystems was livestock grazing. Sheep and cattle grazed the high meadows and floodplains year-round in numbers that far exceeded the capacity of the range (Platts 1991, U.S. EPA 1990). Anecdotal reports and photographs depict summer ranges so heavily stocked with sheep, they appear to be snow drifts. The legacy of this period is still apparent throughout the eastside as evidenced by the terraced hillslopes caused by near constant trodding by millions of hoofs.

As the livestock industry declined after World War I, this similarity in land-use histories for eastern Oregon and Washington diverged. While eastern Oregon developed more rapidly, being along the main migration routes such as the Oregon Trail, most of eastern Washington was relatively isolated. As the livestock industry declined, the timber industry in eastern Oregon expanded to supply the railroads and support the burgeoning population. After World War II, the timber industry boomed, and it has been increasing since then. As an economic base, timber has dominated the forested regions of eastern Oregon.

In eastern Washington, the timber industry developed at a much more moderate pace, not really booming until the late 1970s, as is evident in the land allocations of the Wenatchee and Okanogan National Forests: over 65 percent of their land base is currently under wilderness or roadless designation. Most human development was concentrated in the larger river valleys (the Yakima and Wenatchee), where irrigated orchards and croplands were the economic base.

Based on this information, along with data on changes in fish habitat and the relative health of fish runs in these two regions, fish habitat appears to be in far better condition in eastern Washington than in eastern Oregon. This argument is further strengthened by the stable condition of anadromous runs in eastern Washington, with the exception of the Yakima system; anadromous species in eastern Oregon are listed as threatened species or of special concern (see Nehlsen and others 1991). Anadromous runs to these regions are affected both by fishing and by 8 to 10 mainstem Columbia River dams.

These generalizations must be viewed with caution. A broad regional overview of this nature will fail to identify particular known areas of concern. Clearly, fish stocks in the Yakima basin are imperiled, but primarily because of mainstem flow issues and irrigation diversions (Fast and others 1991). On the other hand, anadromous runs to the Wenatchee and Methow River basins appear to be stable, with the exception of summer steelhead. In eastern Oregon, we know of no anadromous runs that are stable. All are declining.

Strategies to protect and restore anadromous and resident fish populations and their habitat must be based on a watershed approach that protects remaining habitat and restores historical habitats (Johnson and others 1991, Reeves and Sedell 1992). Currently, the Forest Service is developing a strategy (PACFISH) to be applied across the range of anadromous salmonids throughout the west (U.S. Department of Agriculture, Forest Service 1992). Restoration activities that deal with issues of forest health must incorporate a watershed strategy that recognizes the critical linkages between the uplands, riparian zones, and fish habitat. Active restoration and protection of eastern Oregon and Washington watersheds is critical if high-quality fish habitat is to be restored and maintained.

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Fire and Weather Disturbances in Terrestrial Ecosystems of the Eastern Cascades

by

James K. Agee

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INTRODUCTION

Fire has been an important disturbance process for millennia in forested wildlands east of the Cascade crest in Oregon and Washington (fig. 1). Records from early explorers and dates of frequent fires measured on many older scarred trees suggest that fires burned at frequent intervals in many eastside forests and grasslands. Historical fire regimes are important to understand because they were part of a set of ecosystem processes and states that appear relatively more sustainable compared to the state of these ecosystems today.

Fire, in these forests, has been described as both “benign” and “catastrophic.” To make such judgments requires an understanding of how fire interacts with wildlands and whether this interaction is desirable. Solutions to the eastside forest health situation will require making both scientific and value decisions. This paper focuses on the scientific aspect of fire and weather disturbances in eastside forests, with discussion in disturbance regimes over the past century or more. Fire has been a variable in both space and time: low to high intensity, frequent to infrequent, and of small to large extent.

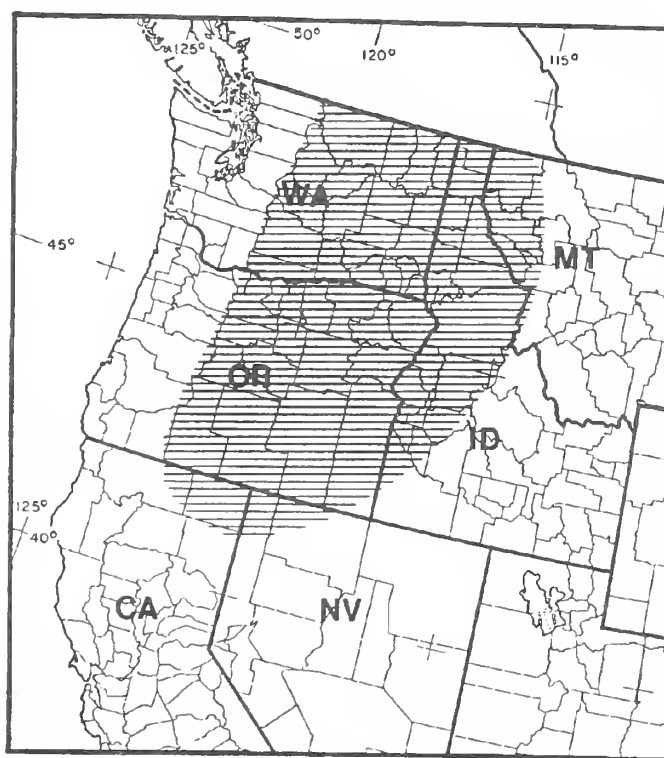


Figure 1. The focus of this review of fire is on ecosystems east of the Cascade crest.

In prehistoric times, some forests burned every 5 to 10 years, but others had fire-return intervals of a 100 years or longer. Fire patterns have changed markedly during the past century. A policy of suppressing all fires, selectively harvesting fire-resistant tree species, and livestock grazing has altered historical fire frequencies, intensities, and extents—collectively known as a fire “regime.” Changes in fire regime, more dramatic in some eastside forest ecosystems than in others, are associated with changes in ecosystem health and sustainability. Using fire in ecosystem management strategies will require addressing some public perceptions and misconceptions about fire and improving forest managers’ ability to predict the effects of fire on landscapes and ecosystem components.

Extreme weather events are much less manageable than fire, but may still have significant impact on stand structures and desired future conditions for eastside forests. Some weather effects, however, are a function of stand structure, so that appropriate management can reduce detrimental effects.

FIRE AS A DISTURBANCE PROCESS

Although natural disturbances of many types have been present in wildland ecosystems for millennia, only recently have scientists begun to quantify their importance in ecosystem structure and function (White and Pickett 1985). During most of the 20th century, the concept of ecosystem disturbance supposed that disturbances must be major and catastrophic. Because they were assumed to originate in the physical environment, disturbances were viewed as an external agent of ecosystem change. In the past two decades ecologists recognized that disturbances spanned a wide gradient of intensities, and many disturbances were at least partly a function of the biotic state of the ecosystem: fuel buildup that affected fire intensity or stressed trees that were more vulnerable to insect attack. Some disturbances, such as insect or disease outbreaks, originate within systems, so disturbance can be an internal agent of ecosystem change.

Fire as a Disturbance Agent

Fire is a classic disturbance agent: discrete in time, affecting ecosystem function and structure, altering the physical environment. Gross generalizations about fire effects are risky, but predictions are possible if fire is described in a specific ecosystem and quantified by its characteristics: frequency, intensity, extent, seasonality, and its relation to other disturbances. Unfortunately, these parameters are not well understood for most ecosystems, including those on the eastside of Oregon and Washington.

The characteristics of fire are important in understanding its direct and indirect effects. Fire frequency, its return interval, is measured by counting years between fire scars on trees or by analyzing age classes of forest stands remaining after fires. Predictability is the variation in frequency. Together, frequency and predictability are important fire characteristics that determine species presence and dominance on the landscape (fig. 2).

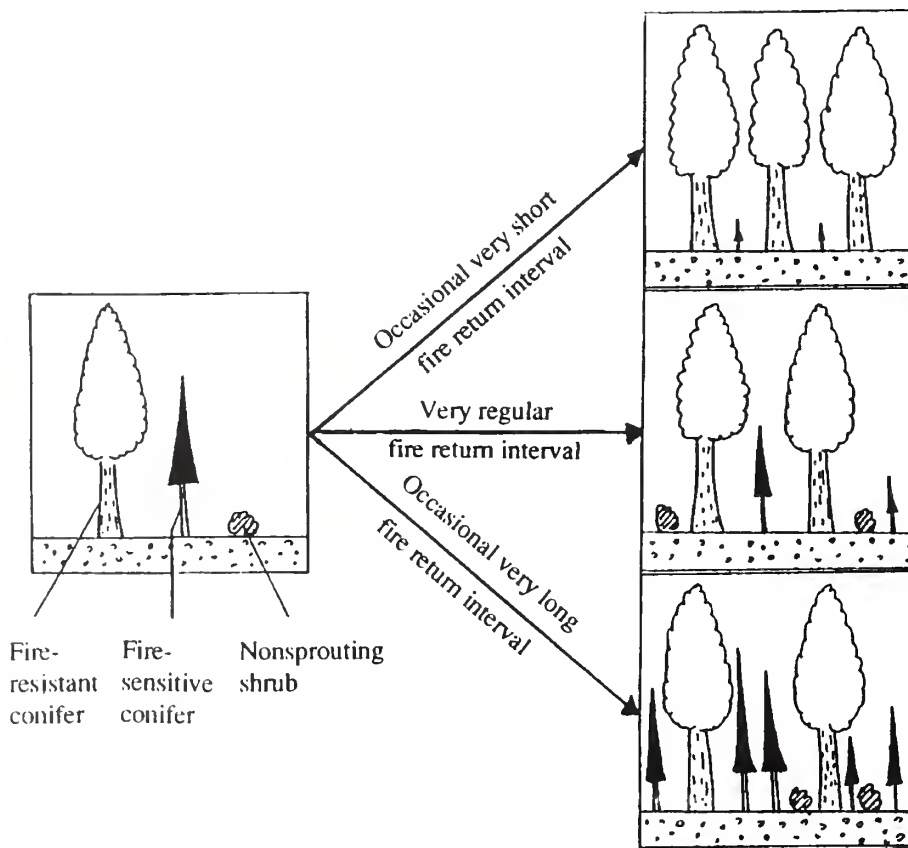


Figure 2. Variation in fire return intervals can result in different vegetation response, even when the mean fire return interval is the same. Short fire return intervals reduce nonsprouting species, and long intervals allow some species to pass through a fire-intolerant stage when young.

The magnitude of a fire is most commonly described by its intensity. Fireline intensity, the heat release rate along a unit length of fire front, is directly related to flame length. In this paper, three categories will be used to describe fireline intensity (FLI). **Surface** fire is the lowest intensity category, with flame lengths to 1 m and FLI below 400 kW m^{-1} . **Understory** fire is of intermediate intensity, with flame lengths between 1 and 3 m and FLI between 400 and 1600 kW m^{-1} . Heat and smoke can be excessive, and fire behavior can be erratic. **Crown** fire is the highest intensity category, with flame lengths above 3 m and FLI above 1600 kW m^{-1} . Many historical (pre-1850) eastside forest fires were in the surface fire category, but historical fires span the entire range of intensities, including crown fires. The ability of some species to either survive or regenerate after fire is significantly related to fire intensity.

The geographic extent of historical fires is poorly known. Cross-dated fire scars can be used to develop maps of fire extent in ecosystems with frequent low-intensity fires. Even this technique is incomplete because such fires would not have scarred every tree within the fire perimeter. In ecosystems that historically burned with high fire intensity, fire extent may be obvious for a century or more from the mosaic pattern of different-aged stands. Most fires east of the Cascade crest must have burned during the summer when lightning strikes were common and fuels were dry. Without fire suppression, fires may have burned sporadically from time of ignition until October or November.

Fire often interacts synergistically with other disturbances. Low-intensity frequent underburning may discourage bark beetle outbreaks by controlling stand density and reducing competitive stress on residual trees. Conversely, fire may encourage bark beetle attack on damaged trees. By creating open landscapes, intense fires increase the effect of rain-on-snow events by making more of the snow-covered landscape susceptible to the impact of warm raindrops. Stand-replacement fires can increase erosion by reducing fine-root biomass that held marginally stable soil in place. Fires inhibit some fungi and dwarf mistletoe through the effects of smoke (Parmeter and Uhrenholdt 1976), but encourage butt decay by opening wounds for entry of decay organisms. Synergistic effects of fire and other disturbance factors make fire a fascinating and complex disturbance.

The Fire Regime

A fire regime is a generalized way of integrating various fire characteristics. The organization may be according to the characteristics of the disturbance (for example, Heinzelman 1973), dominant or potential (climax) vegetation on the site (Davis and others 1980), or fire severity, the magnitude of effects on dominant vegetation (Agee 1990). In this paper, fire regimes will be defined at historical scales by the potential climax vegetation (for example, the grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and by fire severity within each climax series (fig. 3, 4). Changes to fire regimes resulting from management activities will also be discussed.

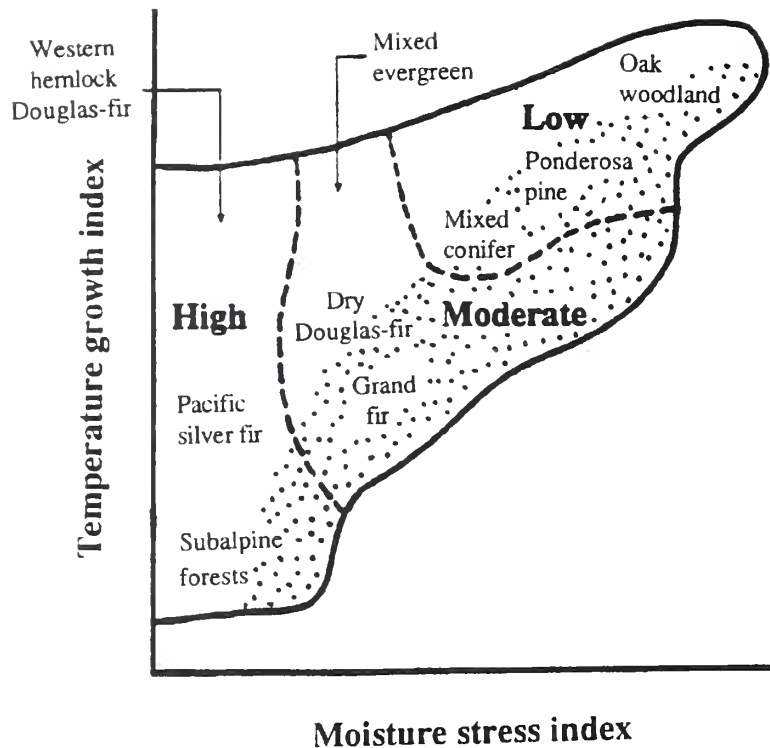


Figure 3. The fire severity regimes of the Pacific Northwest (Low, Moderate, High) can be displayed in the matrix of Pacific Northwest forest types (based on potential climax vegetation) ordinated by growing-season temperature and moisture stress (Agee 1990). Eastside ecosystems are indicated by a stippled pattern.

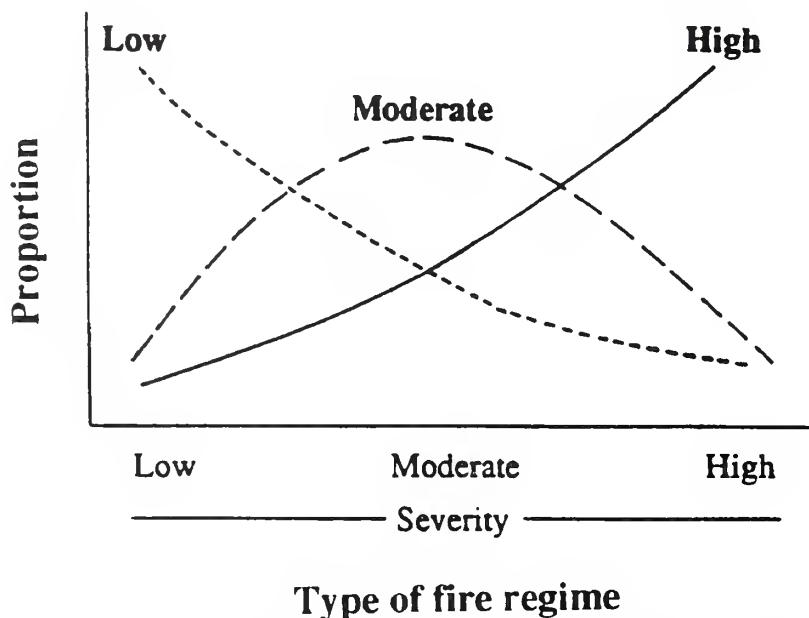


Figure 4. Within each fire severity regime is a range of fire severities, either in the same fire or between fires (Agee, in press).

In the low severity fire regime, the predominant fire severity level results in tree basal area reductions of 20 percent or less. Low severity surface fires are most common, but moderate and high severity fires are possible, although uncommon. At the other end of the scale, in the high severity fire regime, the predominant fire severity level results in tree basal area reductions of 70 percent or more. A high proportion of fires are of understory and crown intensity. The middle of the scale is the moderate severity fire regime,

with a complex mixture of low, moderate, and high severity fires. Historically, eastside forests had all three natural fire regimes.

Fire severity, being defined in part by its effect on ecosystems, is also a function of plant responses to fire. Many plants have adapted to particular fire regimes by developing survival mechanisms.

Fire Adaptations of Plants

Fire has predictable effects on each plant species and time-temperature sequences can be estimated from fireline intensities. These estimates have been used to predict crown scorch height (Van Wagner 1973) and cambial damage (Peterson and Ryan 1986). Predicting root damage is more difficult because of variations in rooting patterns and soil properties. Fire has interacted with individual plant species for millions of years, plants and trees have developed a variety of adaptations to fire, some of which allow them to persist even in the presence of fire; others allow the population to persist even though individuals may be killed (Kauffman 1990). Many plants in eastside forests have such adaptations.

Thick bark is a common adaptation to fire found in trees, particularly where fires were frequent and of low-to-moderate intensity. In eastside forests, mature ponderosa pine (*Pinus ponderosa* Dougl. ex Laws), western larch (*Larix occidentalis* Nutt.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) are insulated for an hour or more against lethal temperatures because of their thick, corky bark, which is a better insulator than asbestos of equal thickness (Martin 1963). This adaptation is most effective in low-intensity fires, which do not scorch the crown but may smolder at the base.

Many shrubs and deciduous trees respond to fire by releasing dormant buds under the bark of fire-scorched stems and branches. This epicormic sprouting occurs when fire is intense enough to kill the live foliage but does not persist long enough to create temperatures lethal to the vascular cambium. Mountain dogwood (*Cornus nuttallii* Audubon) and Oregon ash (*Fraxinus latifolia* Benth.) are examples of such species. Basal sprouting also occurs in many epicormic sprouting species; in other species, such as snowberry (*Symphoricarpos albus* (L.) Blake), ninebark (*Physocarpus malvaceus* (Greene) Kuntze), Scouler's willow (*Salix scoulerana* Barratt ex Hook.), huckleberries (*Vaccinium* spp.), pinegrass (*Calamagrostis rubescens*) and rabbitbrush (*Chrysothamnus* spp.), basal sprouting occurs from root crowns or rhizomes. New growth of some grasses, such as Sandberg's bluegrass (*Poa sandbergii* Vasey) and bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith), is well-protected from frequent, low-intensity fires by older foliage.

Other species are adapted to long-term survival, even though current populations are killed by fire (Kauffman 1990). The important seral shrub ceanothus (*Ceanothus* spp.) and the herbaceous lupine (*Lupinus* spp.) produce seeds that can lie dormant for decades awaiting scarification by fire. After fire, high densities may be found in locations where no live individuals existed at the time of the fire. A similar seed-bank strategy is exhibited by the serotinous cones of some varieties of lodgepole pine (*Pinus contorta* Dougl. ex Loud.), except that the seeds are stored in the canopy of the tree. Seeds are protected beneath resin-sealed cone scales and can remain viable until a fire passes through and melts the resin seal. Trees may die but seeds are undamaged and fall to a newly fertilized ashbed. Some plants are stimulated to flower after burning, such as Great Basin wildrye (*Elymus cinereus*) or pinegrass. Others have wind-blown seed that rapidly invades burned sites, such as fireweed (*Epilobium angustifolium* L.). These adaptations ensure that some vegetative recovery or reestablishment is likely after fire passes through an ecosystem (Stickney 1990).

The Fire Environment

Eastside forest ecosystems exhibit numerous adaptations to a classic "fire environment"—a set of environmental conditions conducive to the recurring presence of fire. Fire behavior can be predicted based on fuels, weather, and topography. Ignition from lightning and by Native Americans over the past few millennia, together with factors influencing fire spread and behavior, have shaped landscape composition and structure. A brief summary of important fire behavior components is presented to help interpret fire effects information for eastside plant series.

A source of fire ignitions with an extended evolutionary track is lightning. Eastside forests are “hotspots” for lightning storms (fig. 5). Based on historical data, variation in fire activity would be expected even within plant associations, depending on location. Higher frequency lightning locations should have shorter fire return intervals than locations with lower lightning potential. August has the highest potential for lightning ignitions (USDA Forest Service 1981).

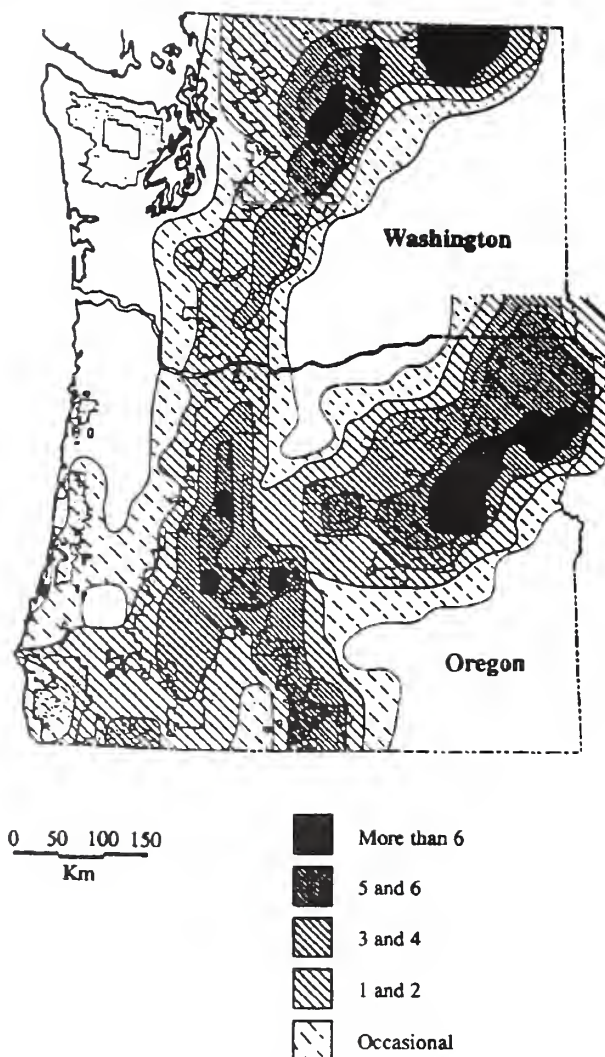


Figure 5. Lightning activity across Oregon and Washington (from Morris 1934). The Blue Mountains, north central-Washington Cascades, and Okanogan Highlands are “hot spots” for lightning.

Once a fire occurs, fire behavior is a function of fuels, weather, and topography. Throughout the low elevation grasslands, woodlands, and forests, grasses and forbs were important fine fuels that allowed surface fires to spread. After European settlement began around 1850, heavy livestock grazing significantly decreased these fuels. At all elevations, dead conifer needles on the forest floor remain important vectors for fire spread. At high elevation, fire spread is augmented by live shrub and tree foliage, but these fuels are only available late in the growing season or during droughts (Williams and Rothermel 1992). Because changes in vegetation correspond with changes in elevation, the plant series is a useful way to describe fuel profiles, but the location and extent of a plant series often require local interpretation (in addition to the lightning patterns described above). For example, the historical effects of fire in a small patch of grand fir forest surrounded by cooler, wetter subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forest will be markedly different than if the small patch were surrounded by drier, warmer ponderosa pine forest.

Weather is important also for patterns of precipitation and wind that affect fire behavior. Protected from Pacific storms by the Coast and Cascade mountain ranges, the eastside forests receive much less precipita-

tion than mountain ranges to the west. Forests near the Cascade crest, adjacent to the Columbia River and in the northern Blue Mountains, are more maritime (not as cold or hot; more precipitation) than other eastside forests, which are more continental (hotter and colder; less precipitation). Most of the annual precipitation, which ranges from 10 to 250 cm, is received between late fall and early spring, while summer precipitation is usually light.

Local winds associated with differential heating of the landscape are important throughout eastside forests: up-valley winds during the day, down-valley at night (Schroeder 1970). Topographic influences interact with weather, but have direct effects on fire as well. Steep slopes are more prone to burn than flat ones, southerly aspects more than northerly, and ridgelines more than valley bottoms. Warm, dry foehn or Chinook winds are common in eastside forests. They occur several times a month during the summer and fall and can quickly dry the fine fuels that carry fire. Such winds can also be strong. Valleys that trend east-west, with low saddles at their crests are more often affected by these wind patterns than are north-south valleys or areas with more topographic relief.

An important exception to typical up-valley afternoon winds occurs in major drainages that flow from the Cascade crest to the east. Daytime heating of the Columbia basin creates a thermal low which draws air from the relatively higher pressure areas of the adjacent Cascade mountains. This configuration creates a down-canyon afternoon wind, which can significantly affect fire behavior (Schroeder 1961). Older trees in the Entiat and Chelan valleys of north-central Washington have fire scars on their down-canyon sides. Because fire scars usually occur on the lee sides of trees when a fire is windblown, and because most fires spread fastest in the afternoon, such scars are evidence of historical afternoon down-valley winds. A recent example of afternoon down-valley winds occurred at the Prophecy fire near Crater Lake, when a thermal low east of the incident area created a strong afternoon wind drawn across the Cascade crest to the east, allowing a fire to burn down-valley at high intensity across several hundred hectares.

Forest fires do not normally consume all aboveground biomass, although they can in ecosystems composed primarily of fine fuel, such as grasslands or chaparral. In forested ecosystems, a higher proportion of dead fuel than live fuel is consumed because moisture contents of the dead fuels are generally lower. Normally, more small than large fuel is consumed, although some exceptions occur (see section on lodgepole pine forests). Biomass available as fuel may be as little as 15 percent of the total aboveground for westside Cascade fires (Fahnestock and Agee 1983) but might be somewhat higher for eastside forests. Most fuel consumption is aboveground, but old stumps and roots will commonly burn out in eastside ecosystems.

Each fuel size class has a different surface-area-to-volume ratio (SA/V), and is thereby able to gain and lose moisture at a unique rate. This ability is characterized in a concept known as timelag class, a descriptor of the time required for a cylindrical fuel particle to move 63 percent of the way to a new equilibrium moisture content. Fine fuels, those below 0.63 cm diameter, have a large SA/V , requiring only 1 h to move 63 percent of the way to a new equilibrium moisture content. They are therefore called 1-h timelag fuels. For example, a 1-h timelag fuel at 10 percent moisture, placed in a drier environment where the equilibrium moisture content is 5 percent, will be at about 7 percent moisture after 1 h. Fuel size classes and their timelag equivalents are: 1-h timelag, 0-0.63 cm; 10-h timelag, 0.64-2.54 cm; 100-h timelag, 2.55-7.62 cm; 1000-h timelag 7.63-20.32 cm. In the field, environmental conditions are always changing, as are moisture contents of the various timelag classes of fuel. During dry summer months, 1-h and 10-h timelag fuels are typically at 5 to 10 percent moisture by dry weight, 100-h timelag fuels at 10 to 15 percent, and 1000-h timelag fuels at 13 to 18 percent.

Live fuels also contribute to fire behavior. Waxy-leaved shrubs often burn in surface fires, and coniferous tree crowns may combust under severe fire weather or dense stand conditions. New leaves typically have more than 200 percent moisture (2 g water/g of tissue), but as the growing season progresses, cell walls thicken and moisture content decreases, so that moisture of late-season leaves is around 100 percent. Older foliage and small twigs remain at that percentage. Foliage above 120 percent moisture rarely burns (Chandler and others 1983). Unusual weather or fire conditions can drop live fuel moisture below 100 percent, and foliar flammability seems to increase once fuels are Z percent moisture content (Agee, in press).

The density of fuels affects oxygen supply and can affect fire behavior. Fuelbeds can either be too dense or too loose to provide optimum oxygen flow or heat transfer. The “packing ratio,” or proportion of the fuelbed volume occupied by fuel particles, can range from grassland (0.001) to tightly packed litter (0.1).

Computerized models of fire behavior have been developed that integrate the effects of fuels, weather, and topography on spread, heat release, and intensity of wildland fires (Rothermel 1983). A variety of standardized fuel models characterize typical grass, shrub, or timber-dominated fuels (Albini 1976). When one of these models is selected or a site-specific fuel model is developed (Burgan and Rothermel 1984), fuel moisture of the timelag classes (below 1000-h) can be entered, as well as live fuel moisture, slope, and windspeed. Outputs include rate of spread and fireline intensity (Burgan and Rothermel 1984); fireline intensity is directly related to scorch height (Van Wagner 1973).

The components of fire behavior influence fire effects. Current fire models focus on the flaming front, but they do not provide sufficient resolution for modeling precise fire effects, such as tree mortality or smoke production. They are helpful in interpreting the eastside forest landscape, however, and suggest how alternative management uses of fire might be modeled in the future.

HISTORICAL FIRE REGIMES OF EASTSIDE ECOSYSTEMS

The historical fire regime is described by those combinations of fire severities that occurred before significant European influence, generally before 1850. We can argue that the influence of horses imported to the continent by Europeans in the 1700s might require an earlier date, but little evidence exists in eastside forests that significant European influence was exerted until after 1850. Historical fire regimes are influenced by a long-standing history of Native American ignitions.

Evolution of Present-Day Vegetation

Long-term climatic changes have caused individual plant species to migrate across landscapes, and fire regimes have changed correspondingly. Little paleoecological exploration has been done in eastside areas compared to other areas of North America, but enough is known to understand major plant migration during the late Holocene (Barnosky and others 1989). The pollen record of the Okanogan Highlands in eastern Washington, near the terminus of the continental ice sheet at the end of the last glaciation, provided evidence of widespread sagebrush-grass vegetation at that time with isolated pockets of forest tree species, including haploxylon pine (the soft or white pines, such as whitebark (*Pinus albicaulis* Engelm.) or western white pine (*P. monticola* Dougl. ex D. Don) and spruce and fir. Present-day relict species, such as the small riparian population of Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) at the Cedar Grove Botanical Area on the Malheur National Forest, were probably more widely distributed. Earlier hypotheses that the Columbia Basin was a lodgepole pine parkland (Hansen 1947) are now dismissed because of the low percentages of diploxylon (hard pines such as ponderosa or lodgepole) pine pollen at most late-glacial sites.

Most sites show evidence of increased summer drought beginning between 11 and 9 millennia B.P. The warmer, drier period commenced and ended at different times across the region. At Carp Lake, a lowland site 150 km west of the Blue Mountains, ponderosa pine replaced steppe vegetation 8500 years ago, and it persists to the present (Barnosky 1985). Similar inferences may be extended to much of the current ponderosa pine series. In more southerly areas of the Columbia Plateau, the range of western juniper has expanded and contracted over the past 5000 years (Mehring and Wigand 1987), suggesting a rough balance in climatic shifts over that time. In subalpine areas, one of the closest regional sites is Lost Trail Bog Pass in the Bitterroot Mountains, Montana, which changed from sagebrush-grass vegetation before 12,000 B.P. to lodgepole pine/Douglas-fir by 7000 B.P. (Mehring and others 1977). During this warming, many boreal species disappeared from eastside landscapes, or moved upslope to form isolated patches, such as Alaska-cedar in the Blue Mountains and the Siskiyou Mountains (Whittaker 1961).

The implication for fire regimes is that individual species have coevolved with fire longer than with any particular plant community. Today's plant communities and their fire regimes represent the environment and species mix of the last few millennia at most. A corollary to this is that if global climate changes, these past fire regimes cannot be projected very far into the future as the operative pattern.

Current Vegetation and Fire Regimes

Today's eastside forests include a wide array of ecosystems, from xeric sagebrush-steppes to alpine meadows (fig. 6). In this analysis, fire history and effects will be described for each of the major vegetation groupings. The plant association concept will be the model by which fire history and effects will be organized. A single plant association will encompass several plant communities on a successional trajectory, but the association is named for the successional endpoint, or climax, community. The climax community is defined by the most shade-tolerant overstory species and understory species that will eventually dominate the site in the absence of disturbance. Disturbances, such as fire, result in seral community dominance; protection from disturbance allows community progressions towards climax.

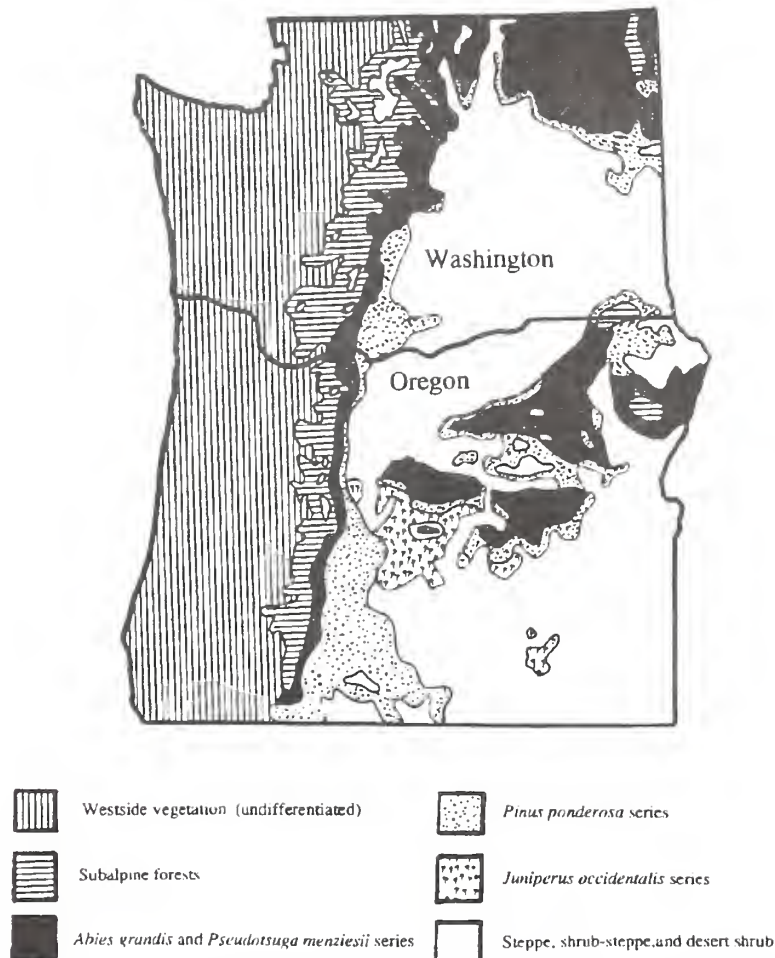


Figure 6. Major vegetation types of eastside ecosystems (adapted from Franklin and Dyrness 1973). The oak woodland type is not mapped but extends in a 50-km-wide band north and south of the Columbia River into the edge of the shrub-steppe type. Nonforested alpine areas are shown as small nonshaded enclosures within the subalpine forest types.

A plant series consists of all the plant associations ultimately dominated by a single, shade-tolerant climax species. Two communities, for example, may be dominated by ponderosa pine in the presence of repeated low-intensity fires. If protected from fire, one might remain dominated by ponderosa pine, although the structure of the community would change; this community would be part of the ponderosa pine series. The other community might become dominated by Douglas-fir and would be part of the Douglas-fir

series. The implications of presence or absence of disturbance on species composition, horizontal and vertical structure, and function are well described by such a classification system.

The tree species occurring across eastside forests are found in more than one of the major plant series (fig. 7). Their adaptations to fire (table 1), in combination with characteristics of historical fires of the past, have resulted in the fire regimes of eastside forests.

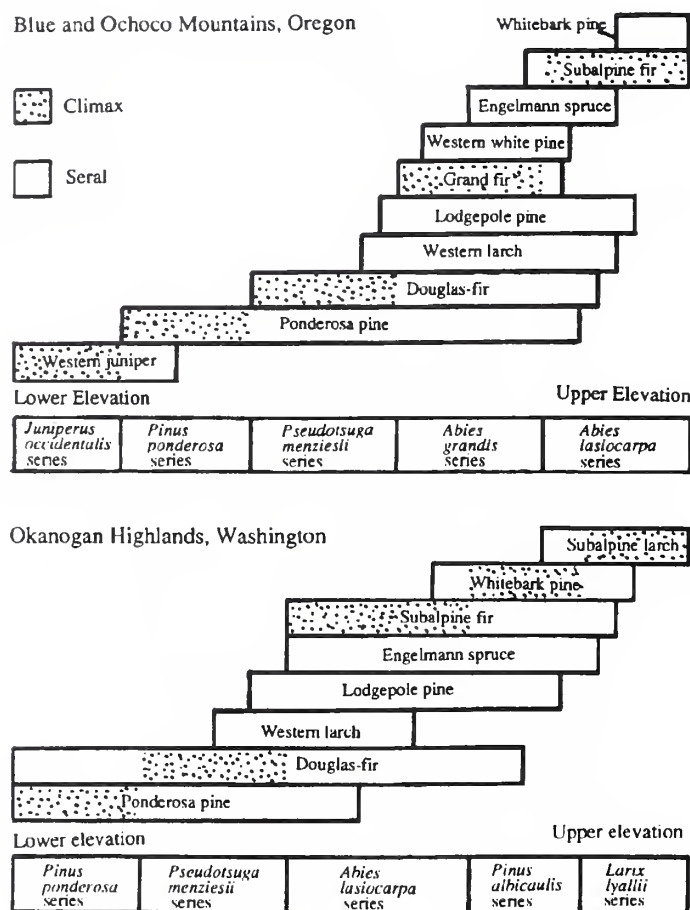


Figure 7. Environmental orientation of the major tree species of two eastside ecosystems. Length of bar denotes range of species, with stippled areas that portion of the range in which a particular species is climax. Top. The Blue and Ochoco Mountains (from Johnson and Clausnitzer 1991). Bottom: The Okanogan Highlands (Williams and Lillybridge 1983). Individual species such as ponderosa pine are found over a broader range of plant series than the one in which it may be a climax dominant.

Table 1—Major tree species of the Eastern Cascades and their response to fire

Tree species	Response to fire
Western juniper	Avoider -- easily killed at young or mature stages
Oregon white oak	Resister -- has thick bark, can also sprout new crown if scorched (endurer)
Ponderosa pine	Resister -- has thick bark that develops at an early age
Douglas-fir	Resister -- has thick bark when mature but susceptible to fire when young
Western larch	Resister -- has thick bark and develops at an early age
Grand fir	Avoider -- thin bark when young but moderately resistant when mature
Lodgepole pine	Evader -- thin bark even when mature, but has serotinous cones (var. latifolia)
Quaking aspen	Endurer -- thin bark, easily top-killed, but sprouts readily after burning
Subalpine fir	Avoider -- thin bark, shallow-rooted, almost always killed by fire
Engelmann spruce	Avoider -- same as subalpine fir
Mountain hemlock	Avoider -- same as subalpine fir
Whitebark pine	Moderate resister -- thin bark but usually grows in fuel-limited environments with patchy fire

The major fire regimes are discussed in related groups. The grassland, shrubland, oak woodland, and the western juniper (*Juniperus occidentalis* Hook.) series are grouped. The ponderosa pine series and lodgepole pine series are discussed separately. The western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western redcedar (*Thuja plicata* Donn ex D. Don) series, which are not widely distributed across eastside landscapes, the Douglas-fir, white fir (*Abies concolor* (Gord & Glend.) Lindl. ex Hildebr.), and grand fir series, and the subalpine fir and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) series, are discussed as combined groups. Riparian areas are discussed as a "group" because of their importance in eastside landscapes, although they are intermixed as linear corridors within the series mentioned above.

Fire History Methods for Eastside Ecosystems

Almost all of the vegetated land east of the Cascades has burned repeatedly over the past 1000 years. Delineating that fire history is sometimes difficult because most of the information must be salvaged from living trees. Grasses retain little evidence of fire, and long-lived shrubs may be useful in dating only the last fire by estimating the age of germinated plants or sprouts from the root crown. More quantified estimates of fire return intervals are available for forested sites.

Two types of fire interval estimation have been used to determine forest fire history: point and area estimates (Agee, in press). Point intervals are used in low-severity fire regimes where fire-scarred residual trees are common. For example, the scar record of an individual tree is an estimate of point frequency, although not all fires will scar every tree. The record of an individual tree is a conservative estimate of fire return interval. Fire scar records of nearby trees may be combined (if crossdated to be synchronous) to produce a better estimate of point frequency, called a "composite fire interval," though this combined record is now distributed over an area rather than a point (table 2). If too wide an area (generally over 10 to 15 ha) is selected, the composite fire interval loses its relevance as an estimate of point frequency. Where fire regimes are of moderate-to-high severity, various area frequency methods are used to determine fire history. These methods rely on reconstructing past fires by age classes of stands over the landscape (natural fire rotation, Heinzelman 1973) or by using the present age-class distribution (negative exponential or Weibull distribution, Johnson and Van Wagner 1985).

Table 2—Fire return intervals for the eastside Cascades major plant series. Some of the cited studies are from related vegetation types in nearby regions

<u>Fire return interval, years</u>	<u>Method [1]</u>	<u>Location</u>	<u>Source</u>
Western juniper series			
15-20	CFI	Nevada	Young and Evans (1981)
7-17	P	N. California	Martin and Johnson (1979)
25	CFI (260)	S.W. Idaho	Burkhardt and Tisdale (1976)
Ponderosa pine series			
16-38	CFI (16)	E. Oregon	Bork (1985)
7-20	CFI (16)	E. Oregon	Bork (1985)
11-16	P	E. Oregon	Weaver (1959)
3-36	P	E. Oregon	Soeriaatmadja (1966)
Douglas-fir series			
7-11	CFI (20)	E. Washington	Wischnopske and Anderson (1983)
10	P	Blue Mountains	Hall (1976)
10-24	P	E. Washington	Finch (1984)
14	CFI (40)	E. Washington	Finch (1984)
8-18	P	E. Washington	Agee (unpublished data)
White fir series			
9-42	CFI (1)	S. Oregon	McNeil and Zobel (1980)
9-25	CFI (16)	C. Oregon	Bork (1985)
9-18	CFI (1)	C. California	Kilgore and Taylor (1979)
Grand fir series			
16.6	CFI (25)	E. Washington	Schellhaas (pers. comm.)
47	P	E. Oregon	Weaver (1959)
33-100	CFI (30)	E. Washington	Wischnopske and Anderson (1983)
17 [2]	P	Montana	Arno (1976)
100-200 [3]	--	Montana	Antos and Habeck (1981)
Lodgepole pine series			
60	P	S. Oregon	Agee (1981)
60	P	S. Oregon	Stuart (1984)
Western hemlock/Western redcedar series			
50-200+	CFI (100)	N. Idaho	Arno and Davis (1980)
50-100 [2]	--	Montana	Davis and others (1980)
150-500 [3]	--	Montana	Davis and others (1980)
Subalpine fir series			
25-75 [2]	--	Montana	Barrett and others (1991)
109-137	NFR	C. Washington	Agee and others (1990)
140-340 [3]	--	Montana	Barrett and others (1991)
250	--	E. Washington	Fahnestock (1976)
50-300 [4]	CFI	Montana	Arno (1980)
29 [4]	CFI (100)	Montana	Morgan and Bunting (1990)

[1] P = point or individual tree, CFI = composite fire interval, with size of area in parentheses, NFR = natural fire rotation

[2] Intermediate intensity fire return interval

[3] Stand-replacement fire return interval

[4] Stands dominated by whitebark pine

(1) * Stands are 70 percent *Abies grandis* series, 20 percent *Pseudotsuga menziesii* series, 8 percent *Tsuga heterophylla* series, and 3 percent *Abies amabilis* series

Many fire history studies have been completed in eastside forests or in neighboring areas where information is applicable. These studies will be discussed by plant series. An important limitation of the fire return interval is the analytical method used. Several unpublished studies are also included in the discussion.

Natural landscape-scale patterns of the various vegetation types are described. At the landscape scale, these patterns are largely unquantified for eastside forests, so I present these sections as unreferenced and speculative. The speculations consist of a set of hypotheses that I think are reasonable given the empirical evidence for patterns of stands. The "natural landscape" is arbitrarily defined here as pre-1850, to contrast changes resulting from management over the past century.

GRASSLAND, SHRUBLAND AND WOODLAND ECOSYSTEMS

Fire History

Little knowledge of historic fire frequency in grasslands, shrublands, and woodlands of the Columbia Basin is available. The scrubland plant series, such as the stiff sagebrush (*Artemisia rigida* (Nutt.) Gray)/Sandberg's bluegrass, Sandberg's bluegrass/oatgrass (*Danthonia unispicata*), *Eriogonum douglasii*/Sandberg's bluegrass, and *E. strictum*/Sandberg's bluegrass plant associations have such low biomass productivity (125-335 kg/ha, Johnson and Simon 1987) that they will not carry fire and probably rarely burned. The green fescue (*Festuca viridula*) (1000-1100 kg/ha), Idaho fescue (*Festuca idahoensis*) (400-1350 kg/ha), and bluebunch wheatgrass (425-950 kg/ha) plant series (Johnson and Simon 1987) have enough fuel to burn annually but probably did not because of low flammability early in the season and lack of fire starts across grasslands late in the season. Native Americans were probably an important ignition source because they were observed in the 1830s setting fire to the prairies of the Blue Mountains (Shinn 1980). In 1826, the Ogden party noted Native Americans setting fire to prairie within 10 m of their camp in the upper Crooked River area near present-day Paulina, Ore. (Shinn 1980). Fires must have also spread from adjacent forest, at least from those forests where fires were frequent.

Little is known about burning in eastside shrub communities. Occasional types such as the *Eriogonum* spp./*Physaria oregana* have too little fuel to carry fire, but many of the rest burned periodically. Long fire return intervals are suggested by accounts cited in Vale (1975), in which early travelers in the Walla Walla area noted 15-cm-thick sagebrush large enough to be used as fuel. Because sagebrush is very fire sensitive, a long fire return interval is inferred from plants this large. Daubenmire (1970) claimed that no record of Native American burning existed for the sage-steppe region of eastern Washington, but Shinn's (1980) accounts suggest such ignitions were at least locally important. Some shrubfields resulted from high-intensity fires on forested sites; these areas will be discussed as early seral communities of those series.

No information is available on oak woodland fire regimes east of the Cascade crest. Information in westside oak woodlands is largely from sites where Douglas-fir is climax, and in eastside oak woodlands north and south of the Columbia Gorge, where ponderosa pine and Douglas-fir are usually the climax species. Native American burning is well documented for such sites (Boyd 1986), and similar burning must have occurred in eastside oak stands. Burning every several years kept pine from encroaching into oak woodlands, allowing easy acorn gathering. Fire return intervals, though unknown, must have been short and intensities low. Extent of the fires is unknown but may have been substantial given the dry conditions and historical abundance of grassy understories.

Western juniper has expanded its range into grassland-shrubland communities over the past century. Most juniper older than 100 years are found on fuel-limited sites, such as rimrock, and most fire history data are from these rimrock sites. Historical fire return intervals in the western juniper series range from a minimum of 10 to 25 years (table 2) to more than 100 years in places where older juniper with no evidence of fire can be found. The intensity and extent of these fires depends in part on how much sagebrush, juniper, and grass is present. Grassy sites are more likely to burn completely over a wider range of conditions than sites with more shrub and tree cover because of the fuel continuity provided by grasses (Clark and others 1985). Most fires are severe enough to kill nonsprouting sagebrush and western juniper because both species are fire sensitive. The extent of historic fires is not well known, but they had the potential to cover wide areas.

Fire Effects

Grassland—Three major plant series are present in the grassland zone: green fescue, Idaho fescue, and bluebunch wheatgrass. Most of the fire effects described below are inferred from information in Johnson and Simon (1987). In general, grassland communities exhibit increases of forbs with fire, and most shrub communities show increases of grass and forb cover after fire.

Green fescue (*F. viridula* Vasey) is dominant in the high elevation green fescue series. Hot, late-season fires will damage green fescue. Weedy forbs, such as yarrow (*Achillea millefolium* L.), aster (*Aster integrifolius* Nutt.), penstemon (*Penstemon globosus* (Piper) Pennell & Keck) and pokeweed (*Polygonum phytolaccaefolium* Meisn.) are favored by fires, which probably occurred at infrequent intervals.

The Idaho fescue series is a widely distributed plant series with more than 10 plant associations in eastside landscapes. As with the green fescue series, hot, late-season fires favor forbs in these plant associations. Late-autumn fires are often less damaging to Idaho fescue than mid-to-late summer fires. Fires tend to burn within the accumulated fine needle-like culms at the base of the plant and produce temperatures sufficient to kill some of the basal meristematic tissue. In Idaho, return to preburn cover took up to 30 years after summer fires (Harniss and Murray 1973). Fires probably created conditions that favored plant diversity on these sites. Balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.), lupines, Kentucky bluegrass (*Poa pratensis* L.), and yarrow are favored by burning, but harsh paintbrush (*Castilleja hispida* Benth.) and prickly lettuce (*Lactuca serriola* L.) are not adversely affected. Prairie junegrass (*Koeleria cristata* Pers.), a common codominant with Idaho fescue in four plant associations, appears to do well after a fire.

The bluebunch wheatgrass plant series is dominated by bluebunch wheatgrass. This grass is more tolerant of fire than Idaho fescue, and fire stimulates bluebunch wheatgrass flowering and seedset. Associates such as Sandberg's bluegrass, red threeawn (*Aristida longiseta* Steud.), and milkvetches (*Astragalus* spp.) are also favored by burning. Wyeth's buckwheat (*Eriogonum heracleoides* Nutt.), a late seral associate in the higher elevation bluebunch wheatgrass plant associations, is weakened by fire, and prickly pear (*Opuntia polyacantha* Haw.) can be damaged after fire by grazing if its prickles are burned off.

Shrublands—Fire effects depend on the adaptive strategies of individual species. Those that can sprout will grow back quickly and share dominance with grasses and forbs for a shorter period of time than those that do not sprout. Stiff sagebrush, big sagebrush (*Artemisia tridentata* Nutt.), low sagebrush (*A. arbuscula* Nutt.), and curleaf mountain-mahogany (*Cercocarpus ledifolius* Nutt.) are nonsprouters that recolonize burned areas slowly. Bitterbrush (*Purshia tridentata* (Pursh) DC), a weak sprouter, is generally killed outright by summer or autumn fires (Clark and others 1982). All of these species increase with protection from fire, but also become decadent over time.

Other shrub species are moderate to strong sprouters and unless fires are repeated and intense, these other species will regain dominance over 5 to 10 years. Ninebark, snowberry, spiraea (*Spiraea betulifolia* Pall.), and rabbitbrushes are common shrubland dominants that increase after burning.

Oak woodlands—Oregon white oak (*Quercus garryana* Dougl. ex Hook.) is the dominant overstory tree in the presence of regular underburning; its acorns do not need stratification, which may be a limiting factor to oak outside of the maritime influence of the Columbia River corridor. Acorns may germinate in relatively warm, moist autumns, and later freeze during winter. Most acorns are eaten by small or large mammals, so few are left to germinate.

Although Oregon white oak, like most other coastal white oaks, is thought to be a less vigorous sprouter than other oak species, more recent research and observations suggest that sprouting is an important form of reproduction for this species (Kertis 1986, Sugihara and Reed 1987). Intense burning associated with log corridors seems to create favored sites for acorn establishment (Agee, unpublished data). These sites, with substantial disturbance, are also favorable sites for many alien species such as velvetgrass (*Holcus lanatus* L.), tansy ragwort (*Senecio jacobea* L.), and St. John's wort (*Hypericum perforatum* L.). The acorns may sprout and oak becomes established because the acorns are buried and thus protected from predators, because of less initial competition from herbaceous vegetation, or because fire sanitizes the site from fungi.

Because oak sites regenerate from both seedlings and sprouts, stand development patterns are not easily interpreted. Historically, seedlings may have replaced dead overstory oaks once the stems fell and burned in fires, which would probably result in a uniform distribution of oaks on the landscape because of mois-

ture competition inhibiting oak establishment near live trees. More recently, cutting of oaks has resulted in more stump sprout and root sucker establishment, which might be more clumped because of multiple sprouts per stump and more root suckers within the circumference of the rooting platform of the older tree.

Western juniper—Western juniper plant associations contain many of the grassland or shrubland species mentioned above as codominants. In rimrock areas, western juniper has remained prevalent over past centuries because of the rocky substrate and lack of fuel needed to carry intense fires. These locations commonly contain older juniper, many of which are fire-scarred, suggesting a moderate severity fire regime. Western juniper has remained dominant in shifting sand dune ecosystems in south-central Washington, migrating with the dunes over millennia (Long and others 1979). Fire is likely less a factor in the stand dynamics of dune junipers.

Historically, fires at 10- to 25-year intervals confined western juniper to protected microsites, although it also established itself around these sites and in grasslands. Young junipers appear to establish best on "safe sites" (sensu Harper 1977): under shrubs, such as bitterbrush, or under the skeletons of dead and down junipers where they are shaded for part of the day. Such shade can result in daytime temperatures up to 3 to 4°C cooler than on nearby bare ground (Burkhardt and Tisdale 1976). The process of tree invasion into the sage-grasslands was slow; established junipers grow slowly (6-9 cm yr⁻¹) and the sapling stage may last 30 to 40 years (Eddleman 1987). Fires moving across the sage-grasslands at 10- to 25-year intervals would have eliminated western juniper from unprotected microsites.

The crown of an established juniper expands slowly over time, and as it does, herbaceous production declines from shading, litterfall, and soil moisture competition; thus, juniper may create its own fuelbreak. I have seen large trees at John Day Fossil Beds National Monument that have survived multiple fires because of the lack of surface fuels surrounding trees, but smaller trees in a matrix of sage-grassland were killed.

Fire at intervals from 10- to 25-years will stimulate bluebunch wheatgrass, Sandberg's bluegrass, and numerous forbs; with Idaho fescue, such intervals will have neutral or negative effects. Nonsprouting shrubs would be temporarily eliminated and cover of sprouting shrubs would be temporarily reduced.

Natural Landscape Patterns

The natural landscape patterns of grasslands, shrublands, and woodlands in eastside ecosystems are complex. We know that some shrublands burned infrequently, and that shrub-steppe, true steppe (dominated by grasses), and meadow steppe (dominated by broad-leaved forbs and grasses) vegetation all occurred. Fire created seral grassland communities in the shrub steppe types, but shrubs were not part of and did not invade other parts of the steppe because of soil and climatic limitations (Daubenmire 1970). Oak woodlands likely covered similar areas as they do today, but with significantly different structure: fewer oaks and many fewer conifers. These woodlands were true savannas, with scattered mature oaks (perhaps 40 ha⁻¹) in a grass-forb dominated landscape. In contrast, juniper woodlands were absent across much of the landscape they dominate today, existing as rimrock, canyon-edge communities that did not support continuous grass cover.

THE PONDEROSA PINE SERIES

Fire History

The dry forest ponderosa pine series is widely distributed in eastside ecosystems, although ponderosa pine is more common as a seral dominant on cooler, moister sites of the Douglas-fir, white fir, or grand fir plant series. The most comprehensive fire history for the Pacific Northwest ponderosa pine series is based on data from the vicinity of Bend, Oregon (Bork 1985). Composite fire intervals (16-ha areas) ranged from 7 to 20 years at Pringle Butte and 16 to 38 years at Cabin Lake. Fire return intervals of less than 5 years

on individual trees have been documented in Arizona (Dieterich 1980), but such frequent burning has not been documented in the Pacific Northwest. The intensity of these fires appears to have been low. Munger (1917) noted that because of the open nature of ponderosa pine woods of the eastern Cascades, fires were relatively easy to check with a 12-inch-wide fireline. The area covered by individual fires in ponderosa pine forests was probably large, because fuel was available on the forest floor: long-needled pine litter and extensive cured grass in the understory. Bork (1985) was not able to show that fires were extensive: most did not scar trees over more than 16-ha areas, but this lack of scarring could be due to low-intensity fires occurring frequently among thick-barked trees.

Significant interactions exist between fires and other disturbance processes in the ponderosa pine series. Post-fire insect attack is common if fire severity results in substantial basal scorch or crown scorch. A risk-rating system developed for bark beetle attack (Keen 1943) and based on four age and four vigor classes appears to work well for fire-related bark beetle attack in ponderosa pine (Swezy and Agee 1991). Vigorous residual trees may expand their growth rates after fires (Weaver 1959), and young trees can survive up to 75 percent crown scorch with less than 25 percent mortality. Older, low-vigor trees may show poor survival (Swezy and Agee 1991). Fire historically reduced dwarf mistletoe infection by pruning dead branches and consuming individual tree crowns that had low-hanging witches' brooms (Harrington and Hawksworth 1990; Koonce and Roth 1980). Little decay is associated with fire scars in ponderosa pine (Morris and Mowat 1958), although belowground root scarring from burning logs has not been studied.

Fire Effects

Between 10 and 15 plant associations are in the ponderosa pine series with both grass and shrub understories. These understory species provided significant soil moisture competition for small ponderosa pine, with surface soils most affected (Riegel and others 1992). Some shading of seedlings by live or dead trees may be important for protection from heat and frost (Cochran 1970), but height growth of established seedlings was reduced by competition with adjacent mature trees (Barrett 1973). Frequent underburns before 1900 killed most of these small understory trees, which had colonized the sites during brief fire-free intervals, maintaining an open, parklike appearance in ponderosa pine forests. Mature trees were protected from the light fires by high crowns and thick bark.

Stand development of ponderosa pine forests is associated with the shade intolerance of the pine, good seed years, and frequent fire (Cooper 1960). Forest pattern is uneven-aged at the landscape scale, but even-aged at the stand or group scale (Cooper 1960). Gaps are thought to be created by the death of old, even-aged groups of trees (0.06-0.13 ha), which fall and scarify the soil after branches and boles are consumed by subsequent fires. Pines became established on these sites, and lack of pine needle fuel in the gap may have caused it to be missed by the next fire or two, allowing the small trees to develop a little more size and fire resistance before a surface fire eventually moved through and thinned the young landscape patch. The same fires would kill regeneration under mature tree canopies. This regeneration was generally smaller because of the competition from larger trees. It was also subjected to hotter fires because of the accumulated litter from those larger trees. The even-aged pattern was thus maintained within mature groups and new groups formed only in openings. New clusters of trees would be thinned by fire over time and eventually become a "yellow-belly" mature group of ponderosa pine.

Cooper's stand development hypothesis, developed in Arizona, has been slightly altered by White (1985), who found a much broader range of tree ages and more variation in clump size in other Arizona pine stands. In the eastern Cascades, West (1969) found clump sizes of about 0.25 ha in ponderosa pine forests, with regular, uniform spacing of trees within clumps. He hypothesized that elliptical groups were due to fires scarifying the soils along the axes of trees downed by west winds. Morrow (1985) found ponderosa pine cluster sizes from 0.02 to 0.35 ha near Bend, Ore. Surviving cohorts of trees in the 1980s were associated with longer fire-free intervals of the past, suggesting saplings had an increasing probability of survival if they were protected from fire for a cycle or two.

Production of other understory species in these forests is inversely related to tree density and cover. Historically, these open, parklike stands had substantial grass and forb cover (Wickman 1992). Nonsprouting shrubs such as bitterbrush that used to be much more limited in cover because of frequent underburning are now widespread. Although bitterbrush can sprout after light spring burning (Martin and Driver 1983), fire often kills it. Clark and others (1982) showed that spring burned bitterbrush will sprout, with about 15 percent surviving for 1 year, but fall-burned bitterbrush is almost totally killed. Bitterbrush will recolonize sites, often from rodent-cached seed, but fires held the shrub understory in check. Frequent light burning allowed bunchgrasses and most forbs to recover rapidly (Wright and others 1979), so herbaceous vegetation dominated the understory.

Natural Landscape Patterns

The natural landscape pattern of ponderosa pine forests was a seemingly unbroken parkland of widely spaced tree clumps and continuous herbaceous understory. Dutton (1887) romantically described the ponderosa pine forests of Arizona: "The trees are large and noble in aspect and stand widely apart...Instead of dense thickets where we are shut in by impenetrable foliage, we can look far beyond and see the tree trunks vanishing away like an infinite colonnade. The ground is unobstructed and inviting....from June until September there is a display of wildflowers which is quite beyond description." The stable patch dynamics of ponderosa pine forests were largely a result of frequent low-intensity fire. Disruption of this pattern occurred at small scales (less than the 0.35-ha patch size) when trees in patches became senescent or when mistletoe-infested trees torched. Of all the eastside forest vegetation types, the ponderosa pine type was the most stable in landscape pattern.

THE DOUGLAS-FIR, WHITE FIR, AND GRAND FIR SERIES

Mixed-conifer forests are transitional between the drier, lower elevation forest or woodland types, and higher elevation subalpine forest types. The white fir series in the eastern Cascades is a southern extension of the grand fir series, and in fact the two firs hybridize extensively through central and southern Oregon. The white fir series occurs from about Bend, Oregon, south to Crater Lake National Park. The species is more widely represented in the Klamath and Siskiyou mountains and the Sierra Nevada in California. The more mesic white fir series of the Siskiyou mountains is not included in this discussion. The Douglas-fir and grand fir series may locally be absent in eastside forest transects; when they both occur, the grand fir series is found on the cooler, moister sites.

Fire History

The mixed conifer forests of the Douglas-fir, white fir, and grand fir series show the most frequent fire activity of all eastside forests, although cooler, wetter sites of the grand fir series have longer fire return intervals (table 2). In this respect, they are not transitional or intermediate to the lower and higher elevation forest zones, but in fact represent the most frequent fire return interval. Frequent fires in drier plant associations of these series is likely due to higher productivity of fine dead fuels needed to carry another fire compared to the ponderosa pine series.

Fire intensities appear to have been low in the drier Douglas-fir, white fir, and grand fir plant associations where associated dominant understory species were *Carex geyeri* Boott. or *C. pensylvanica* Lam., *Calamagrostis reborescens* Buckl., or *Arctostaphylos uva-ursi* (L.) Spreng.. Longer fire return intervals and higher fire intensities have been found in Douglas-fir forests of the eastern Cascades where the understory dominants were snowberry, ninebark, and *Vaccinium* spp. (Williams and others 1990). This pattern also appears in the cooler grand fir series. In the Elkhorn Range of the Blue Mountains southwest of La Grande, Bork (unpublished data) found individual tree fire return intervals of 50 to 200 years (grand fir/*Vaccinium membranaceum*), and intervals of 66 years and 100 to 200 years (grand fir/*Vaccinium scoparium*) on cool, moist grand fir sites.

Fire Effects

Forests within these three potential climax series have more tree species than the ponderosa pine series, although ponderosa pine was the major seral dominant in many of these forests. In some eastside locations, either one or both of the ponderosa pine or Douglas-fir series is absent, so the transition to forest may be grassland-to-pine or grassland-to-Douglas-fir, or grassland-to-grand fir (Hall 1967).

The white fir series—White fir is the potential climax dominant in these forests, but under pre-1900 conditions in most eastside white fir forests, this species was at most a codominant because of the selective thinning effect of frequent fires. A clumped pattern of stands, often composed of pure species aggregations, was typical of forest structure before European settlers arrived (Bonnicksen and Stone 1981). Thomas and Agee (1986) found clumped distributions of ponderosa pine, sugar pine (*Pinus lambertiana* Dougl.), and white fir in old-growth white fir forests at Crater Lake.

Fire dynamics in white fir forests have been modeled extensively (Kercher and Axelrod 1984, van Wagtenonk 1985). Ponderosa pine is an early dominant in simulations of frequent burning and maintains its dominance through its growth rate, growth form, and thicker bark. More than 50 percent of the basal area is ponderosa or sugar pine.

Descriptions of understory species dynamics in the presence of recurring fire are much like those described for ponderosa pine forests, except that some of the understory species obviously change. The shrubs of these forests are adapted to sprouting after burning or regenerating from fire-scarified seed (Biswell 1973; Kauffman and Martin 1984, 1985, 1991). Although summer and fall burns probably consumed many seeds, such fires also cracked the coats of seeds allowing them to imbibe water and later germinate. Repeated short interval burns favor sprouting shrubs over obligate seeders, as eventually the soil seed supply is exhausted and young plants may not be able to reach sexual maturity before another fire kills them.

The Douglas-fir series—Fire effects in the drier Douglas-fir series with understory dominants like snowberries, pinegrass, and elk sedge are similar to the ponderosa pine and white fir series. Frequent low-intensity fires kept these forests open and parklike, with ponderosa pine present as a seral dominant. Although no information exists on stand pattern, occasional long fire-free intervals allowed some Douglas-fir to grow large enough to resist destruction by fire (Keane and others 1990). The predictability of the fire regime was likely a major determinant of the proportion of Douglas-fir on these sites with occasional longer fire-free intervals associated with more Douglas-fir.

In more mesic Douglas-fir plant associations, a moderate severity fire regime likely mixed low-intensity fires with fires of higher intensity. Understory fires opened larger patches in the forest that were suitable for colonization by species such as western larch. Stand dynamics in a Douglas-fir/ninebark plant association in western Montana were simulated by Keane and others (1990 FIRESUM model). At regular fire return intervals of less than 20 years (fig. 8), Douglas-fir was essentially absent from the landscape because of its low fire tolerance when small. With longer fire return intervals, Douglas-fir became a codominant with ponderosa pine and larch. Most real stands would show a mix of the fire return intervals in figure 8. Some Douglas-fir/ninebark stands of the Okanogan Highlands appear to have had occasional intense fires (Williams and others 1990), suggesting that current models may not incorporate the entire range of fire effects. In the Blue Mountains, it tends to occupy steep, canyon-slope positions that experienced stand-replacing fires (Johnson and Clausnitzer 1991). The Douglas-fir/*Vaccinium membranaceum* plant association likely had a similar fire regime.

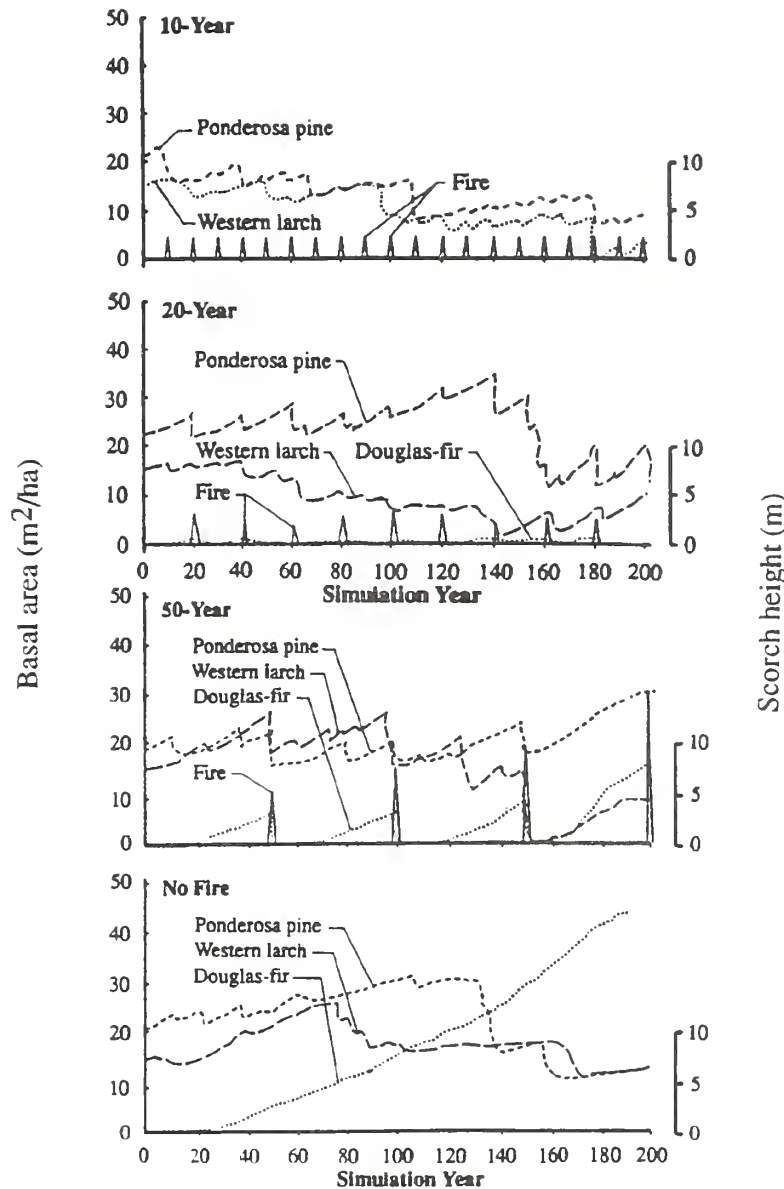


Figure 8. Simulations of relative basal area of species in a Douglas-fir/ninebark plant association under various disturbance regimes (Keane and others 1990). As fire return intervals lengthen, ponderosa pine decreases in importance relative to Douglas-fir. Where grand fir is present, its response would be similar to that shown for Douglas-fir in these figures.

The grand fir series—The grand fir series in the Blue Mountains had a wider range of historical fire regimes than the Douglas-fir series, probably because it appears to replace the Douglas-fir series in places where the latter series is locally absent. The drier grand fir plant associations, with understory dominants such as elk sedge or pinegrass appear to have burned frequently (Hall 1976, Johnson and Clausnitzer 1991). Ponderosa pine and western larch, and to some extent Douglas-fir, were historically more important than grand fir on these drier sites, and rhizomatous shrubs such as snowberry were common shrub associates. No information is available on scale-level pattern that specifically addresses these forest types, but in other mixed-conifer locations, clumping of single species (for example, one group of ponderosa pine, another of true fir) tended to occur (Bonnicksen and Stone 1981, Thomas and Agee 1986).

In the cooler grand fir series, fire return intervals were longer, and the natural fire regimes shifted to moderate severity. Stand-replacement fires were more common. As canopy gaps became larger, early seral regeneration shifted to very shade-intolerant species with special adaptation to fire. Lodgepole pine,

with serotinous cones in some varieties, and western larch, with its thick bark, light seeds, and long lifespan, became important associates of grand fir. The fast, early growth rates of these two species enabled them to become canopy dominants after fire but Douglas-fir and grand fir were relegated to subordinate canopy positions (Cobb 1988). Where intense fires occurred at intervals less than 150 years, lodgepole pine generally shared dominance with other seral species at the site (Antos and Habeck 1981, Gabriel 1976). Repeated, intense burning at long-intervals (100 to 200 years) created nearly pure lodgepole pine stands, which become difficult to assign to plant associations because of the absence of the climax species (Johnson and Clausnitzer 1991).

Lodgepole pine is favored by intense fire at intervals less than 200 years (Williams and others 1990). Either low-intensity fire or absence of fire may favor other species. If a second fire occurs within 20 years after a stand-replacement fire, a stand of lodgepole pine, Douglas-fir, and western larch will lose its pine component because the double burn kills the pine and also eliminates the lodgepole pine seed source (Cattellino and others 1979). The absence of fire for a long time favors longer lived or more shade-tolerant species. Stands without lodgepole pine may have arisen from occasional fire return intervals exceeding 200 years, when short-lived lodgepole pine may have been killed by mountain pine beetles (Haig and others 1941). In the Blue Mountains, major mountain pine beetle outbreaks occurred during 1907-12 (Burke 1990), probably in stands 80 years old that regenerated after intense forest fires in the early 1800s.

Long fire return intervals may be typical of most cool, moist grand fir plant associations with understory dominants such as oak fern (*Gymnocarpium dryopteris* (L.) Newm.), sword fern (*Polystichum munitum* (Kaulf.) Presl.), Rocky Mountain maple (*Acer glabrum* Torr.), and Pacific yew (*Taxus brevifolia* Nutt.). Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) may be present on wetter and colder sites. Most of these locations are lower slope to riparian and may be residual stringers that do not burn as often as the associated uplands. Although Pacific yew is very sensitive to fire, recent observations of seedlings on burned slash units (Ottmar, pers. comm.) suggest it may be more resilient than earlier thought.

Two fires in rapid succession tend to favor shrubs over trees. After the second fire, shrubs will resprout but tree seeds may be lacking. Big huckleberry (*Vaccinium membranaceum* Dougl.) and grouse huckleberry (*V. scoparium* Leiberg.) are two common understory dominants that may share dominance with lodgepole pine after intense fires on moist sites. A second fire in a decade or two will kill the pine before many of the trees have reached sexual maturity, leaving only re-sprouting shrubs and light-seeded herbs on site. Several herbs occurring in mature stands of the grand fir series typically root in the duff and are significantly reduced by fire (Flinn and Wein 1977). These include twinflower (*Linnaea borealis* L.), prince's pine (*Chimaphila umbellata* (L.) Bart), rattlesnake plaitain (*Goodyera oblongifolia* Raf.), and strawberries (*Fragaria* spp.).

Natural Landscape Patterns

The white fir, Douglas-fir, and grand fir series forests, geographically transitional between lower and higher elevation forest, also appear to have had a transitional landscape pattern. No data support these speculations, so these hypotheses are made with sketchy information and limited field observations. On drier sites, these series had a stable structure, disrupted at the small scale of the patch such as occurred in ponderosa pine forests. In all three climax series, ponderosa pine was the dominant on drier sites. From the environmental midpoint of these series to their margin with the subalpine fir series, patch size was probably larger, and more severe fire events at longer intervals occurred. Under severe fire weather, larger patches (larger than 500-1000 ha) were killed. Intermediate-to low-intensity fires separated the stand-replacing ones, breaking the megapatches into smaller patches, thinning according to species susceptibility to fire and density. A more variable spatial and temporal landscape pattern emerged over time than seen in the woodland or ponderosa pine forests.

THE LODGEPOLE PINE SERIES

Climax lodgepole pine forests are primarily topoedaphic climaxes, occurring where no other tree species has a superior competitive advantage, and all but lodgepole pine have a difficult time becoming established. The most continuous block of lodgepole pine forest is in south-central Oregon, where deep pumice deposits from the eruption of Mount Mazama (now Crater Lake) left infertile, coarse material. A limited lodgepole pine series also occurs in the Blue Mountains, where lodgepole pine is the apparent climax species, but it is restricted to frost pocket sites. Whether it experiences the fire regimes of similar but seral stands on warmer sites (Johnson and Clausnitzer 1991) or the more varied interactive disturbance of fire, insects, and disease typical of the lodgepole pine series in south-central Oregon (Gara and others 1985) is currently unknown. Other climax lodgepole pine forests are found in Colorado (Moir 1969) and the Yellowstone plateau (Despain 1983). This discussion focuses on the south-central Oregon populations where the lodgepole pine series is most widely distributed. The dynamics of other lodgepole pine forests, particularly where they are seral, are discussed in each climax series where lodgepole pine is a seral component.

Fire History

Lodgepole pine forests have a moderate-severity fire regime. Multi-aged stands are the rule rather than the exception. The fire history of lodgepole pine forests is complicated by the presence of scars not just from fire but also from mountain pine beetle strip attacks (Stuart and others 1983). The interactions among beetle activity, disease, and fire are complex, and they create multi-cohort stands, not all of which are fire-generated. Nevertheless, Stuart (1984) documented a 60-year fire return interval on the Fremont National Forest, Agee (1981) also found a 60-year interval at Crater Lake National Park, and Chappell (1991) found a 40-year fire return interval in a California red fir (*Abies magnifica* A. Murr.) forest directly adjacent to a lodgepole pine flat. The magnitude of natural fires ranges from crown fires to "cigarette burns," where fires slowly burn along jackstrawed log corridors composed of beetle-killed trees. The stands studied by Stuart (1984) and Gara and others (1985) had an even-aged cohort that appeared to have regenerated after a stand-replacement fire in 1840. Other fires have burned only along logs because these forests have extremely low productivity ($1 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$) and therefore little continuous forest floor.

Fire Effects

In this moderate severity fire regime, a typical disturbance scenario includes selective removal of about a third of the stands every 60 years, either by insects, fire, or a combination of the two. Judging from the mountain pine beetle outbreak in eastern Oregon in the late 1970s and 1980s, the extent of insect attacks tends to remain regional, and is triggered by regional climatic patterns.

Stand development patterns intimately reflect disturbance patterns. When beetles attack a stand, they generally remove large trees with sufficiently thick phloem to support a brood of larvae. The next few years have a greater probability of high-intensity fire than without beetles because of increased fine fuel in the crown or on the forest floor. Fire potential declines until the beetle-killed trees fall, typically in a widely spaced jackstraw pattern. When partially decayed, the logs are capable of sustaining slow-moving, smoldering fires, which often burn corridors only 20 to 30 cm wide across the landscape. Burning logs scar trees (Gara and others 1986) can kill or scar tree roots beneath them. The result is additional stress on adjacent live trees, encouraging another beetle attack, or allowing disease organisms to enter the tree. In subsequent years, beetles prefer to attack trees with fire-related scars or disease (Gara and others 1984). These attacks will create more snags, which provide the vectors for subsequent fires.

Regeneration is commonly found only in areas where competition for soil moisture is low and microclimate is ameliorated, such as the north side of snags or among logs (Stuart 1984). Seedling groups and insect-killed trees are clearly associated (Stuart and others 1989).

Scarce understory vegetation occurs in openings where competition for soil moisture is less severe. Because of the linear or patchy nature of most fires, fires have little effect on understory plants. Grasses,

such as western needlegrass (*Stipa occidentalis* Thurb.) sprout back the next year. Bitterbrush, found on only the more productive lodgepole pine sites, is usually killed by fire (see ponderosa pine series).

Natural Landscape Patterns

Although substantial disturbance occurred in lodgepole pine forests, fire and bark beetle interactions created fairly stable landscape patterns. Some stands were burned in crown fire events, but such fires appear to be limited in extent. More common were fires that left some residual forest structure on the landscape and did not burn at a landscape scale because of patchy fuel continuity. Mountain pine beetle outbreaks, like those of the 1980s, must have also occurred in the past. The landscape pattern was probably quite stable over time, however, with occasional (50 to 100 yr) region-wide decreases in basal area (30 to 50 percent) resulting from widespread insect attack.

THE WESTERN HEMLOCK AND WESTERN REDCEDAR SERIES

The western hemlock series is poorly represented in eastern Washington and nearly absent in eastern Oregon. It is a dominant series in the maritime-influenced areas of the northern Rocky Mountains, where the grand fir series is found on excessively drained sites, and the western redcedar series on wetter and drier sites than the grand fir series (Cooper and others 1987).

Fire History

Fire return intervals are not well known for the western hemlock and western redcedar series, although almost every site contains buried charcoal, fire-scarred western redcedar trees or other evidence of fire. A typical fire return interval for low-to-moderate severity fires is 50 to 100 years (table 2); a stand-replacement interval is 150 to 500 years. Western redcedar forests in hydric locations are less susceptible to burning than western hemlock forests (Daubenmire and Daubenmire 1968). Fire intensity is clearly variable. South of Interstate 90 in Idaho and Montana forest types become more riparian, and they typically burn at lower intensity than the adjacent slope forests. In northern Idaho and northwestern Montana, however, they have been the sites of some incredibly intense fires, most notably the 20,000-ha Sundance fire of 1967 (Anderson 1968). Other extensive fires burned in 1934, 1926, 1919, and 1889 (Cooper and others 1987). In 1910, 400,000 ha burned in these plant series in northern Idaho (Barrows 1952).

Fire Effects

The tree species found in these forests, besides western hemlock and western redcedar, include western white pine, lodgepole pine, grand fir, Engelmann spruce, western larch, and Douglas-fir. Many of the stand development patterns of these forests mimic those of the cooler part of the grand fir series, except that the more shade-tolerant western hemlock is present. Western hemlock is also more shade tolerant than western redcedar (Habeck and Mutch 1973), but evidence suggests that western redcedar can maintain itself indefinitely on the wetter sites (Cooper and others 1987).

Moderate-severity fires kill lodgepole pine, Engelmann spruce, grand fir, and western hemlock on these sites. Western larch, and Douglas-fir, ponderosa pine, western white pine, and large western redcedar will *resist* the fires and are left as residuals. Some western redcedar will often effectively *avoid* severe fire damage by growing in stream bottoms and other moist microsites where fires burn with difficulty (Arno and Davis 1980).

High-severity fires can kill all the trees on the site, and succession will start with a herb-shrub stage (Davis and others 1980); then the successional dynamics are similar to those of the cooler part of the grand fir series, except that the later successional species include western hemlock and western redcedar.

Natural Landscape Patterns

Where the western hemlock series is widespread east of the Cascade range, fire return intervals are long, and older forests predominate. When disturbance occurs, patch size can be 10,000 to 20,000 ha. Where western hemlock forest is confined to moist benches, ravines, and river valleys, fire stops or burns only patches, leaving residual forest as stringers across a landscape of drier forest that burned.

THE SUBALPINE FIR AND MOUNTAIN HEMLOCK SERIES

The subalpine forests of the eastside are predominantly of the subalpine fir series. The mountain hemlock series occurs only in scattered areas immediately east of the Cascade crest, in the northern Blue Mountains, and in northern Idaho.

Fire History

Fire return intervals tend to lengthen to exceed 100 years, and fire intensities tend to increase in subalpine fir (table 2) and mountain hemlock forests. Bork (unpublished report) noted a 40 to 50 year fire return interval in a location transitional from the grand fir to subalpine fir series. In very high, cold environments with late snowmelt, forests dominated by subalpine larch (*Larix lyallii* Parl.) rarely ever burn (Arno and Habeck 1972), and whitebark pine forests have the shortest fire return intervals of eastside subalpine forests (Arno 1986, Morgan and Bunting 1990).

Fire intensities are high in subalpine forests and substantial mortality is the usual result. In the early USGS forest survey reports, the subalpine fir series was the only eastside forest type in which stand-replacing fires were the rule rather than the exception (Gannett 1902, Gorman 1899). Many of the early seral (lodgepole pine) or late seral (Engelmann spruce, subalpine fir, mountain hemlock) tree species are poorly adapted to resist fire. Western larch and mature Douglas-fir, with their thick bark, have been common survivors, (Barrett and others 1991).

No information exists on the size of these prehistoric fires. Fahnestock (1976) found that most fires during the historical period in the Pasayten Wilderness, located in north-central Washington, subalpine fir series were small—only about 15 percent exceeded 15 ha. Two of these larger fires, each burned 10,000 ha, accounting for more than 60 percent of the total area burned. Small crown fires have been observed in the spring while snow is still on the ground (Huff 1988).

Fire Effects

The subalpine fir and mountain hemlock series occupy the coolest eastside forested sites, and the subalpine fir series is, by far, more widespread. Fire tends to kill all the tree species in these forests. Western larch and lodgepole pine were common early seral dominants. The most typical replacement sequence is lodgepole pine, followed by eventual subalpine fir and Engelmann spruce. Because of the cool conditions, growth is generally slow, and replacement may take more than two centuries. Often, another fire occurs before the replacement sequence is complete, and lodgepole pine is again favored.

In the Pasayten Wilderness, Fahnestock (1976) showed lodgepole pine to be the exclusive dominant 50 years after stand-replacing wildfire. Spruce and fir colonized in a relay floristics pattern (for example, Egler 1954), becoming dominant 100 to 200 years after a fire. Some lodgepole pines will persist for up to 400 years on these sites (Fahnestock 1976).

The subalpine fir plant associations with understory dominants such as Queen's cup beadleily (*Clintonia uniflora* (Schult.) Kunth.), twinflower, and fool's huckleberry (*Menziesia ferruginea* Smith) tend to be the most maritime plant associations (Johnson and Clausnitzer 1991). They tend to have the longest fire return intervals, and are most likely to be sites on which seral lodgepole pine has disappeared. If lodgepole

pine has largely been replaced by the time of the fire, shrubs such as the huckleberries may dominate the site for decades after the fire or may share dominance with western larch. Trees may only slowly recolonize such sites, but the huckleberries will eventually decline with increased shading. After 200 years, the only seral evidence of the previous fire will be the long-lived western larch, sharing dominance with generally younger subalpine fir and spruce. If lodgepole pine is present at the time of the fire, then it is likely to be a postfire dominant.

Little is known of fire effects in the eastside mountain hemlock series because it has such a limited distribution. Stand-replacement fires favor lodgepole pine, yet old-growth stands of mountain hemlock without much fire evidence suggest some stands have not burned for many centuries. In the Oregon Cascades, Dickman and Cook (1989) found that fire fragmented laminated root rot (*Phellinus weirii* (Murr.) Gilbertson) root disease centers in mountain hemlock by favoring *Phellinus*-resistant lodgepole pines after large stand-replacement fires.

In timberline stands, whitebark pine may be a codominant with subalpine fir. Crowns may not close on these sites if disturbances such as fire, snow avalanches, and rockfalls, prevent it. Scattered vegetation is conducive to whitebark pine survival after fire, and trees may escape with only scarring. Clark's nutcrackers are known to cache pine seeds in burned areas from trees in adjacent unburned areas (Tomback and others 1990). In stand-replacement burns, this practice allows whitebark pine to colonize sites first. Subalpine fir is slow to become established because of its large seeds which are not wind-dispersed long distances. Fire often recurs before whitebark pine has disappeared (Morgan and Bunting 1990).

Natural Landscape Patterns

Stand-replacing fires of variable size appear to be the fire pattern of the subalpine fir and mountain hemlock series. The frequency distribution of fires approaches a negative exponential distribution (many small fires, few large ones). In terms of total area, the few large fires will represent the dominant patch age in any river basin, so that the age-class distribution of fires is not represented by a negative exponential distribution. The fire interactions in Pacific Northwest subalpine forests are not equilibrium, steady-state processes, and the patterns will likely vary considerably drainage by drainage. This behavior is much less common for lower elevation forest series.

Subalpine sites are marginal for tree establishment and growth. Depending on the extent of the fire and the weather that follows it, substantial burned areas may remain treeless for decades unless a seed source of lodgepole pine is present at the time of a burn. Where lodgepole pine is present, tree cover is usually rapidly reestablished. Modeling patch sizes created by fire and regeneration that follows is more complicated and variable than modeling for lower-elevation forests.

FIRE EFFECTS IN RIPARIAN AREAS

A riparian area is in contact with or adjacent to open water. In the western States, riparian vegetation is estimated to occupy about 1 percent of the forest (Clary and McArthur 1992), and in the Blue Mountains, riparian areas are estimated to cover about 2 percent of the forest (Kauffman 1988). Though riparian areas occupy a very small proportion of the forest, they have a disproportionate importance in natural resources issues. Besides supporting aquatic organisms, riparian areas are the most productive timber and forage sites and consequently, are constantly used by wildlife.

Fire affects riparian zones both directly and indirectly. Direct effects are those associated with burning within the riparian zone. Indirect effects arise from burning outside the riparian area, which affects transport of sediment, biomass, or water through the riparian zone. Both types of effects can be characterized by knowledge of the fire regime and the type of riparian system. Riparian zones often represent the

down-canyon extension of a higher elevation plant series (fig. 9). Cold air drainage at night and less insolation make these areas cooler and moister than associated slopes.

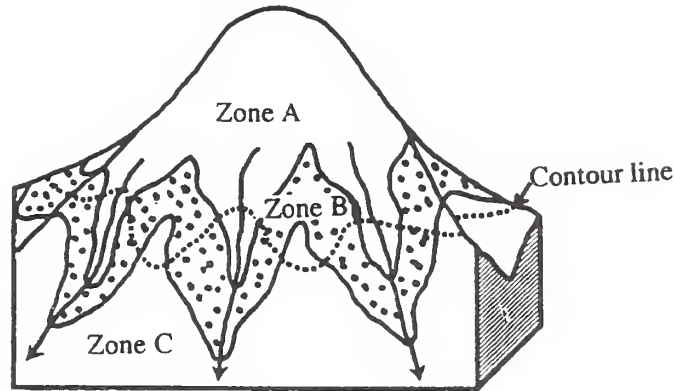


Figure 9. Interfingering of vegetation zones on a mountain slope. Because of less insolation and cool airflow at night, riparian areas tend have vegetation often found at higher elevation on slopes or ridges (from Franklin and Dyrness 1973).

The direct effects of various disturbance types on riparian systems (fig. 10) was conceptually modeled by Agee (1988). Floods have a wider effect where floodplains are better developed and streams are larger. More incised, smaller riparian areas have less wind disturbance because topography breaks up wind patterns. In general, riparian areas do not burn or they burn at reduced intensity, because they are wet sites with more deciduous vegetation and higher dead and live fuel moistures. This generalization appears to hold in coastal spruce forests (Agee and Huff 1980), Douglas-fir forests of the Oregon Cascades (Swanson 1981), spruce-fir forests of the Rocky Mountains (Romme and Knight 1981), and western redcedar forests of Montana (Habeck 1978). Determining fire return intervals is complicated by the presence of riparian tree wounds from ice flows (Filip and others 1989, Rosentreter 1992) and the short life spans of most riparian hardwood species. The riparian zones of drier areas probably did burn more frequently. In the Blue Mountains along the Oregon Trail, early travelers noted riparian groves of aspen and willow that had been recently burned (Evans 1991).

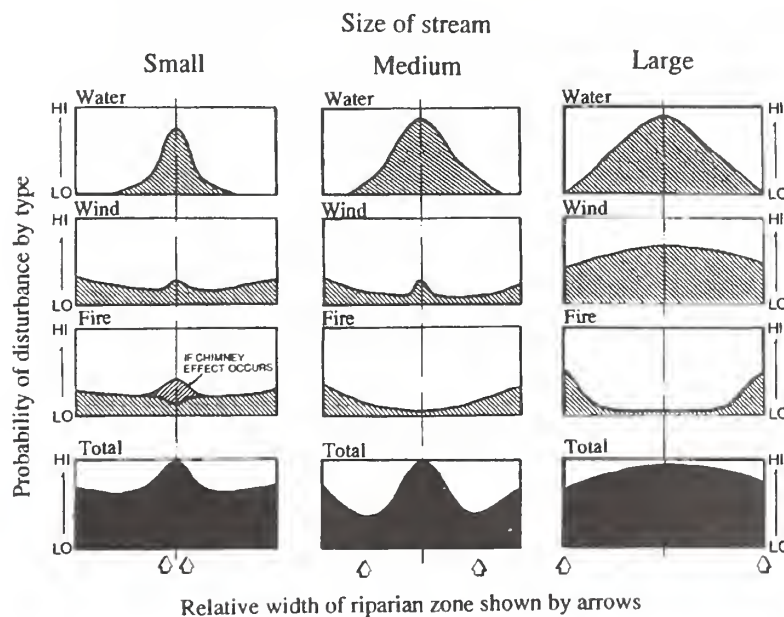


Figure 10. A model of riparian disturbance patterns. Relative probabilities of water, wind, and fire disturbances for small, medium, and large stream systems are shown. The "total disturbance" probability (at bottom, black) suggests that the lowest probabilities of disturbance are at the edges of medium stream channels and perhaps away from the floodplain of large streams (from Agee 1988).

Headwater riparian areas sometimes burn with greater intensity than surrounding slopes because of a channeling effect of wind in an area of generally higher biomass than elsewhere. Some of the hottest burn sites in the 1988 Dinkelman fire near Wenatchee were in riparian areas.

If a small fire creeps through a riparian area, it often topkills most shrubs and deciduous trees, such as willows and cottonwoods, but because most of these species re-sprout, soil stability is not impaired. Regrowth will eventually replace much of the shading effect at the stream edge. Large ponderosa pine, Douglas-fir, or western larch easily survive such fires, and western redcedar often does so by growing in wetter microsites. Engelmann spruce and subalpine fir, present at higher elevations and in cooler riparian zones, are almost always killed. A fire of similar intensity will thus have a more severe effect on tree mortality at high elevation if these conifers are a part of the riparian zone that burns.

In higher severity fires, even riparian stringers are killed. The 1970 Entiat fires left almost no riparian zone along the Entiat River, although scattered western redcedars survived along the bank. Little shading (compared to pre-burn) is present there after 20 years or more. Further upslope in the same watershed, hillslopes were covered with ponderosa pine and Douglas-fir, in the Douglas-fir series. Fire scars on stumps and stump ages of several hundred years indicate the multi-age-cohort stand had frequent low-intensity burning. Yet the riparian area in the creek bottom directly below was an even-aged stand of lodgepole pine, which regenerated after a stand-replacement event about 1900. This example provides more evidence that riparian zones may burn less frequently but occasionally more intensely than the surrounding slopes.

EFFECTS OF EXTREME WEATHER ON EASTSIDE FOREST ECOSYSTEMS

Weather is considered part of the environment to which native vegetation has become adapted. Most discussions of disturbance (White and Pickett 1985) are vague when it comes to defining when changes in environmental parameters become disturbances. Usually, the definition includes a subjectively defined parameter—for example, “substantial.” In this discussion, I consider unusual weather events that affect growth or survival of eastside vegetation.

Unusual Temperature

Excessive temperatures are important for their absolute value. Additionally, high or low temperatures can occur at critical times, causing damage or mortality to forest vegetation.

Vegetation damage associated with unusual cold weather is often preceded by unseasonably warm temperatures, which have either prevented cold hardening of the foliage of plants or initiated meristematic development of tissue. Recorded temperature extremes have often provided improved competitive advantages for some vegetation, rather than widespread killing of all vegetation. One cold snap in early November 1955, occurred after an unseasonably warm period. Forests on the west side of the Cascades were affected more than eastside forests, with significant damage to western hemlock and western redcedar and widespread killing of red alder (*Alnus rubra* Bong.) and Pacific madrone (*Arbutus menziesii* Pursh.) (Duffield 1956). By contrast, eastside forests escaped relatively unscathed, although truck and orchard crops were significantly damaged (Torbitt 1956).

In January 1989, unseasonably warm weather was followed by extreme cold-temperatures below -30° C were recorded in interior British Columbia. Buds had probably already met their chilling requirements, and cell division had begun in meristematic tissue, with an associated loss of cold hardiness (van der Kamp and Worrall 1990). Douglas-fir, white spruce, Engelmann spruce, and subalpine fir suffered cold damage above snow level, with younger trees being hit harder than older ones. The most significant damage was

recorded on western redcedar; surprisingly, little damage was recorded for western hemlock. Lodgepole pine, noted for its cold tolerance, was unaffected.

A poorly documented form of cold damage, which can occur in eastside forests that are heavily fertilized, affects development of cold hardiness in autumn. Trees in experimental plots in the Mud Creek drainage of the Entiat River, fertilized with the equivalent of 400 lbs ac⁻¹ urea N, have been almost totally killed within plot boundaries. The delay in cold hardiness is an indirect effect of high N content, which causes changes in translocation of substances affecting cold hardiness. Trees die from the top down over a period of several years. In red spruce (*Picea rubens* Sarg.), increased N has been associated with increased cold tolerance in needles but decreased cold tolerance in buds (L'Hirondelle and others 1993).

Damage from excessively high temperatures on mature trees is rare, although mortality of seedlings from high daytime temperatures is common (Daubenmire 1943). High temperature damage in eastside forests is periodically observed during winter months. A phenomenon called "red-belt" (Bega 1978) has been observed every few years in the Entiat River drainage at about 900-m elevation. On cold, snow-covered ground, the ability of trees to absorb water in their roots and to translocate it is low. A temperature inversion associated with either cold air drainage from higher elevation in the mountains or penetration of cold Columbia Basin air, together with a Chinook or foehn warm wind, desiccates a thin band of foliage directly above the inversion layer. The dead foliage is brown in the spring, although buds are usually not affected and produce normal foliage. Such damage must be associated with loss of growth, but leader death is rarely observed. In Colorado, a red-belt effect in lodgepole pine was associated with only 1 percent tree mortality; 97 percent of trees exhibited new growth the following season, and bark beetles did not attack them (Schmid and others 1991).

Unusual Wind

Windstorms of sufficient magnitude to cause widespread blowdown are rare in eastside forests. Some of the strongest winds are from the north, but the mountainous terrain tends to reduce wind intensity. No information was found in the literature on widespread windthrow in eastside forests (Agee and Edmonds 1992). In 1955, a strong wind knocked over a ponderosa pine, killing a camper in a trailer in Yakima County (Phillips 1956). The westside suffered more treefall and powerline failure, however.

Wind-Temperature Interactions

Winter winds are associated with foliage die off on windward sides of subalpine trees, creating asymmetrical crowns or krummholz, where leader growth continually dies back, and trees are shrub-like. Winter desiccation of needles may be less important than abrasion of cuticular wax by wind-blown particles, which reduces the needle's ability to retard moisture loss. When the relative needle moisture declines below 60 percent (MPa moisture stress), needle death is likely (Hadley and Smith 1986). As with most other weather disturbances, this effect is more important for its influence on the trees ability to compete with other vegetation than as a cause of death. Desiccation surely causes some seedling mortality on windblown subalpine ridges, however.

Unusual Moisture Status

Unusual moisture may take the form of above- or below-normal amounts of precipitation, as rainfall or snow. The regional drought of 1920-40 in the Pacific Northwest created substantial insect infestation problems, particularly for pines, and Keen (1937) investigated tree-ring records of eastside forests to attempt to relate the magnitude of this drought to past droughts. He found evidence of drought back to the 1200s, with more recent droughts in 1917-36, 1870-93, 1839-53, 1795-99, 1777-88, 1756-60, and 1739-44. Graumlich (1987) showed that the timing of regional droughts differs by subregions in the Pacific Northwest: the Columbia basin is not always synchronous with the western lowlands of the west Cascades or the southern valleys of southwest Oregon and northern California. Synchronous droughts over the last three centuries occurred in 1973, 1929, 1899, 1839, 1739, 1721, and 1717. Evidence suggests that droughts and forest fires occur together, although the predictive ability is not strong.

Rain-on-snow events melt the snow and often cause major flooding. Riparian areas can be detrimentally affected by bank erosion and streamside sloughing. Exceptional snows can cause damage to tree crowns, either by breaking branches of mature trees or deforming leader growth of young trees (Williams 1966). Generally, however, excessive moisture has a positive effect on forest growth because of the amelioration of a regionally limiting environmental factor—lack of water.

An interaction between stand structure and snow falls can lead to increased damage to the “doghair” thickets (very high densities of spindly small trees) of trees that now occur in many eastside forests. Many of these doghair stands are a result of fire suppression and removal of larger canopy dominants through selective harvest. Because of excessive density, stems continue to grow in height but not diameter. After a heavy snowfall, or if the stand is open on one side, these doghair trees will break off because they cannot sustain the additional weight on the crown. This action begins at ratios of crown height to stem diameter of 100:1 (for example, 100-inch tall tree at 1-inch diameter; Oliver and Larson 1990), but breakage from additional snow can occur at ratios below 100:1. This problem will only exacerbate with time because this kind of stand stagnation rarely corrects itself.

EFFECTS OF FOREST MANAGEMENT ON FIRE REGIMES

Management practices that have had the most significant effects on fire regimes in eastside forests are fire suppression, livestock grazing, and selective tree harvesting. Other activities, such as pest suppression and wilderness fire management, have had a much less noticeable effect. They are covered in a paper by Oliver and others (1993).

Fire Exclusion Policy

Near the beginning of the 20th century, the European tradition of forestry began to be seen as a model for American forestry. In this context, fire was considered a major threat; consequently, new legislation was enacted to protect forests (for example, the Weeks Act of 1911). Additionally, fires from land clearing and other activities had threatened lives and property as well as timber reserves, and those who argued for fire suppression pointed to these problems in making their case. Ironically, as fire was being institutionalized on the west side of the Cascades to reduce slash after logging, it was being eliminated as a management tool in the eastern Cascades where its historical effect had been much more frequent.

The battle over whether fire should be used as a management practice was staged in the pine forests of northern California between 1910 and 1925. The Southern Pacific and Red River timber companies were using low-intensity, prescribed fire to manage their pine timberlands, but this practice was decried as “Piute [sic] forestry,” a tactic meant at the time to imply poor management. The issue was discussed in *Sunset Magazine* in 1920 (Graves 1920, White 1920). The Forest Service argued that fires killed regeneration under the larger trees, which led to the end of light burning by the end of the 1920s. Few people foresaw that successful regeneration could eventually lead to increased wildfire control and forest health problems.

Two courageous professionals attempted to show the long-term detrimental consequences of such a fire policy beginning in the 1940s: Harold Weaver of the Bureau of Indian Affairs in the eastern Cascades of Oregon and Washington (Weaver 1943), and Harold Biswell of the University of California in the pine forests of that State. Both encountered tremendous resistance within their profession, but near the end of their careers in the 1970s, both saw a change in attitude within the profession (Biswell 1989). Changes in attitudes about fire have not resulted in its being put to use, however. Most use of fire into the 1990s has been associated with activity fuels on harvest units over a small proportion of the landscape (for example, Kilgore and Curtis 1987).

Timber Harvesting

Timber harvesting has historically focused on the more important commercial species, ponderosa pine and western larch. Early harvesting activities concentrated on only the largest trees because merchantability

standards did not allow smaller stems to be efficiently processed. Lower elevation stands in the ponderosa pine, Douglas-fir, white fir, and grand fir series were selectively logged for pine and larch. In general, these early seral species were removed, usually leaving smaller climax species to capture the growing space.

In more recent decades, a wider suite of species has been used, including grand fir, lodgepole pine, and subalpine fir. Smaller diameter material has increasingly been harvested for processing into wood chips.

Livestock Grazing

Settlement of the Oregon Territory and associated livestock grazing began in the late 1830s. By 1860, 200,000 cattle were settled in Oregon, along with sheep and wild horses (Galbraith and Anderson 1991). By the winter of 1861-62, the practice of yearlong open range with no shelter or hay storage was being questioned. In the Walla Walla Valley, dead cattle were so numerous at the end of that winter that a person could almost step from one dead animal to another throughout the whole valley (Galbraith and Anderson 1991). Harsh winter weather did not recur for 20 years, so yearlong open-range grazing continued until 1889-90 when another bad winter forced cattlemen to accept the need for food and shelter in winter.

Sheep were increasing on eastern Oregon rangelands in the 1890s, in part because they were cheaper to raise than cattle. Bands of sheep wandering on already overgrazed ranges led to range wars in the early 1900s. The Sheep Shooter's Committee of Crook County claimed to have shot 8,000 to 10,000 sheep a year during that time (Galbraith and Anderson 1991). Grazing laws were developed for National Forests by 1910, but much of the damage had been done (Harris 1991). The rangelands had evolved without substantial grazing pressure, but intensive grazing significantly damaged the perennial bunchgrass ranges.

Effects of Past Management Practices on the Landscape

Because the natural fire regimes of eastside forests were interrupted by the combined effects of these management practices, ecosystems changed—some experienced only minor changes, but in others, the changes were catastrophic and probably irreversible.

Grasslands, shrublands, and woodland ecosystems—The perennial grasslands surrounding the Blue Mountains have been subjected to severe overgrazing; alien species, in particular the annual cheatgrass (*Bromus tectorum* L.), have increased as a result. Cheatgrass germinates in the autumn in this region and maintains a rosette form as it develops a root system during the winter (Young and others 1987). It can use much of the available soil moisture before perennial grasses initiate new growth in the spring. Cheatgrass completes its life cycle in late spring to early summer, and the fine-textured cured foliage is highly flammable. This trait has expanded the historical burning season in some areas, which has only increased the dominance in these sites by annuals (Whisenant 1990). In contrast, intensive grazing elsewhere has removed perennial grass fuels and reduced the ability of fire to spread.

Over the past century, with effective fire exclusion, eastside oak woodland has been invaded by ponderosa pine. Because oaks are more shade-intolerant than pine, they will be killed as the pines grow above them. This pattern is common with Douglas-fir and oaks in westside Cascade valleys (Habeck 1961, Thilenius 1968). Oak woodlands have significantly declined across the Pacific Northwest. This vegetation type might expand significantly with global warming if the gene pool survives, but significant conifer invasion has already occurred. Some oak woodlands will become extinct over the next 25 years unless conifers are selectively removed and light burning is used to control conifer re-invasion.

Most oak woodlands were associated with perennial grassland understories, which were well-adapted to periodic light underburns after the current-year foliage had cured and roots had stored carbohydrates. Oak woodlands have always been favored livestock grazing areas, because both forage from grasses and shade from trees are present. Grazing of perennials, which have not had significant ungulate grazing pressure since early in the Holocene (Daubenmire 1970), together with the introduction of alien grasses such as cheatgrass have irrevocably altered the understories of oak woodlands. Increases in tree cover have

favorable shrubs and forbs over grasses. Restoration efforts, by tree removal or fire, will inevitably favor alien species, although cessation of grazing in westside oak woodlands has been associated with recovery of some perennial natives (Saenz and Sawyer 1986). All of the northern Oregon white oak woodlands are threatened unless action is implemented in the next decade. At best, only partial recovery can be expected.

Western juniper has doubled its range since 1860 (Burkhardt and Tisdale 1976). Several hypotheses attempt to explain this expansion: climatic change favoring juniper; recovery from logging of juniper during European settlement; overgrazing by domestic livestock, opening up competition-free microsites for juniper; and the absence of fire, which would otherwise kill fire-sensitive western juniper. Expansion has been slower on big sagebrush sites than on low sagebrush sites (Young and Evans 1981).

The climate-change hypothesis has shown that juniper pollen (and presumably juniper abundance) in eastern Oregon has varied over the past 10 millennia as much as in recent times (Mehring and Wigand 1987), but the hypothesis provides no climatic evidence for the recent expansion. The logging recovery hypothesis is locally valid in mining districts (Hattori and Thompson 1987) but not regionally important, many areas invaded by junipers show no stumps or other evidence suggesting junipers existed there in the recent past. The overgrazing hypothesis is tenable, but juniper invasion has occurred even in ungrazed areas (Quinsey 1984). Overgrazing might interact with the absence of fire because herbaceous fuel decline would restrict fire spread.

The most plausible single hypothesis is fire exclusion. Historical fires killed junipers by basal or crown scorching. Intense summer wildfires kill nearly all junipers; individual fires under more moderate weather conditions can leave more residuals (Martin 1978). Prolonged herb and shrub stages have been observed on burned western juniper sites (Everett 1987). A return to natural fire regimes would reduce but surely not eliminate juniper across the eastside woodlands. It also would have positive hydrologic effects for this dry landscape (Eddleman and Miller 1992).

The ponderosa pine series—Forests of the ponderosa pine series changed in several significant ways over the last century. The landscape development pattern of clumped groups of even-aged trees was interrupted by fire protection (Morrow 1985), allowing regeneration to survive not just in openings but under mature clumps. A widespread, fire-protected age class of ponderosa pine has colonized the landscape, creating doghair thickets of pine trees in many areas, with many trees no more than several centimeters in diameter after 60 to 80 years. This dense understory has created additional dry-season moisture stress on the older trees. Where the older trees have been removed, the younger residual stands are too dense and have stagnated, making them susceptible to attack by western pine beetle (*Dendroctonus brevicornis* LeConte) and mountain pine beetle (*D. ponderosae* Hopkins) (Gast and others 1991). An outbreak of beetles could increase fuel loading and thus fire hazard. Where these younger stands have been mechanically or manually thinned, the risk of beetle outbreaks is reduced (Sartwell and Stevens 1975), although pine engraver beetles (*Ips pini* (Say)), which breed in the thinning slash, may cause additional mortality if adequate slash is unavailable when the beetles emerge.

Where once-frequent surface fires were carried through pine stands by needle litter and grass, they are now carried by needle and branch fuels. The vertical continuity of fuelbeds has also increased over time which allows surface fires to develop into understory or crown fires under moderate weather conditions. At the same time that average fire intensity is increasing because of fuel buildup, average fire tolerance of stands has dramatically decreased because of overstocking and stagnation.

The increase in tree density, together with intensive grazing, has caused a decline in shrub and herbaceous understory. Understory production in ponderosa pine forests is inversely related to tree crown cover (Pase 1958) or other measures of tree competition such as basal area, litter depth, or tree density. With dense tree canopies, forbs are favored over grasses (McConnell and Smith 1970). Once-common grasses such as Idaho fescue, bluebunch wheatgrass, and Sandberg's bluegrass have declined, also in part because of heavy grazing. In Montana, Idaho fescue was absent in grazed stands (Evanko and Peterson 1955). Aver-

age herbaceous production in open, mature stands has probably declined from 1000 to 1500 kg/ha to 100 kg/ha or less (Biswell 1973).

Increased needle litter can replace grass as a fine fuel to carry fire. However, thick tree understories are associated with decreased average windspeed, higher relative humidity, and higher dead needle moisture content in these altered stands, so that fire spreads under fewer weather conditions. On balance, an interaction—in a statistical sense—occurs between fuels and the weather: under moist conditions, fire will not carry through stands it once burned freely across; under dry conditions, it burns much more intensely than in the past. A low-severity fire regime has been converted to a fire regime with a moderate-to-high severity.

The white fir, Douglas-fir and grand fir series—Some of the most visible landscape changes have occurred in these three plant series, particularly on the drier sites. The structural changes noted for the ponderosa pine series have also occurred in these series, but they have been accompanied by a major shift to more shade-tolerant species. These mixed-conifer forests are experiencing the most severe forest health problems (Gast and others 1991).

The duration and intensity of outbreaks of the western spruce budworm (*Christoneura occidentalis* Freeman) appear to have increased with this shift in species composition to budworm-sensitive species (see Lehmkuhl and others 1993, Hessburg and others 1993). In Montana, stands in the Douglas-fir series once dominated by ponderosa pine are now dominated by Douglas-fir. As fire return intervals have lengthened during this century, budworm outbreak duration has increased from 8 to 13 years to 17 to 29 years, and outbreak severity (on a relative scale of 0-1) from 0.41-0.53 to 0.63-0.70 (Anderson and others 1987). Similarly, Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)) outbreaks have been most common at the low elevation border of the Douglas-fir and grand fir series (Williams and others 1980), or on ridgetops or south-facing slopes (Mason and Wickman 1988), where, in the past, frequent fires kept Douglas-fir subordinate to ponderosa pine. The first outbreaks known to the Blue Mountains were noted in 1928 (Gast and others 1991), although the tussock has likely been present at low populations for long periods of time. Favoring nonhost species such as ponderosa pine is the most effective control measure for both defoliators (Mason and Wickman 1988).

In most dry mixed-conifer forests, effective fire suppression resulted in filling all of the growing space with trees by about 1960 (McNeil and Zobel 1980), unless larger trees were subsequently harvested. Many trees more than 30 to 40 years old are less than 1 m tall (Agee 1983), and trees in these multilayered forests with a suppressed understory are highly susceptible to budworm attack. This increase in tree density has also had effects on stand pattern and understory production.

The architecture of mixed-conifer stands has changed both horizontally and vertically. The spatial pattern of a mosaic of several species, with each containing a single clump species, has been replaced by the density of a single (Douglas-fir, white fir, or grand fir) shade-tolerant species (fig. 11) (Agee and Edmonds 1992, Thomas and Agee 1986). Where little harvesting activity has occurred, the past pattern of vegetation is sometimes still discernible in the older trees, which suggests that the old pattern may be recoverable with intensive thinning. Where the early seral species such as ponderosa pine or western larch have been removed, thinning will not help to restore a past pattern. Large openings will be required to encourage natural or artificial regeneration of these species (Mutch and others 1993). Vertical continuity has increased in these stands similar to that seen in the ponderosa pine series, and most of the added layers are composed of shade-tolerant species. Site-specific evidence of these changes has been documented by Schellhaas and others (pers. comm.). In mixed-conifer locations in the eastern Washington Cascades, they found high tree density, with 70 percent of the trees in cohorts from the fire-exclusion period. Of about 1400 trees ha⁻¹, only 85 ha⁻¹ are above 40 cm diameter.

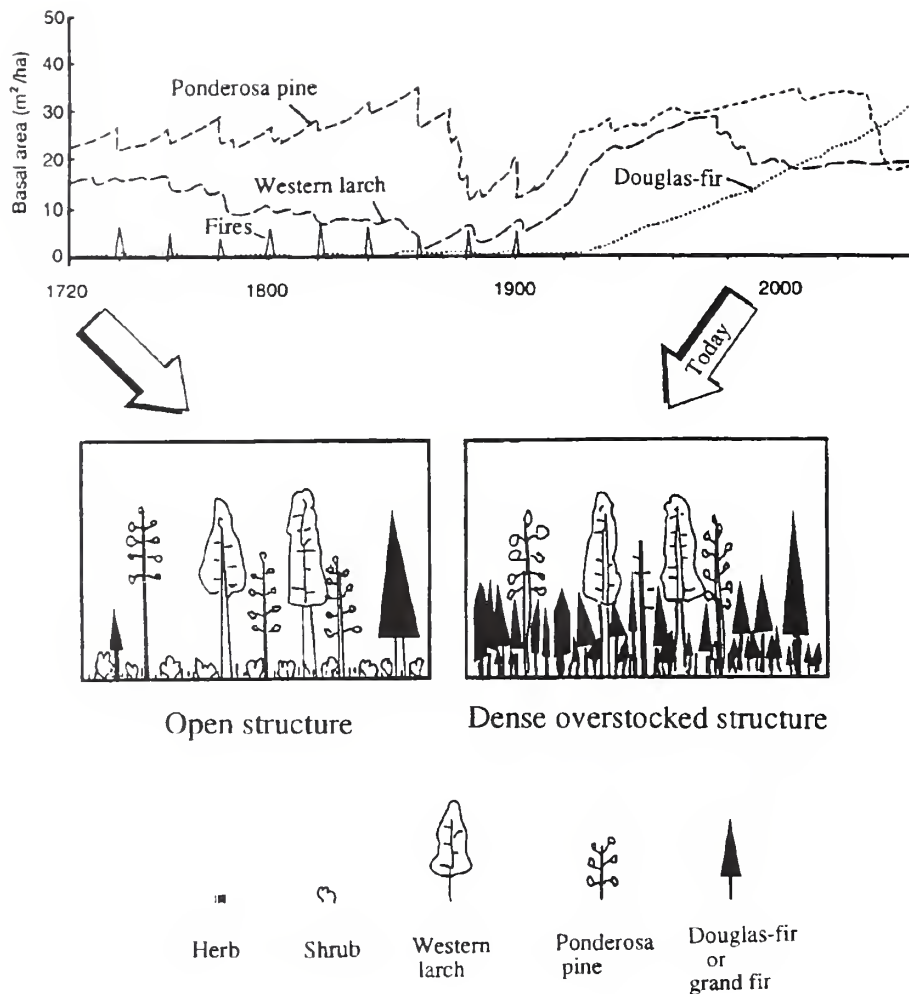


Figure 11. A simulation of ecological change in Eastern Cascade mid-elevation forests resulting from successful fire exclusion. This graph was constructed by combining from figure 8 the results of the 20-year fire return interval up to the year 1900, and then the no-fire simulation after 1900. Shade-tolerant trees now choke the understory. Little precedent for current forest structure is apparent (from Agee and Edmonds 1992).

A human-induced shift from low-severity fire towards moderate-to-high severity fire has occurred in the drier portions of the Douglas-fir and grand fir series. An example of increased fire intensity is the Dinkelman fire near Wenatchee in 1988. Trees that had many fire scars, indicating survival of many past forest fires, were killed in a severe fire. One dead tree had not been scarred by fire since 1889, with about a century of fuel buildup to accentuate fire intensity. Before 1889, the length of fire-free intervals was 19, 10, 10, 20, and 13 years, which would have maintained understories free of tree regeneration. All young trees that had come in since 1889 were also killed. A related example is the Dooley Mountain fire along Highway 245 south of Baker City, Ore. that killed most trees. The large size of ponderosa pine and Douglas-fir trees across the burned area suggests that the trees survived many fires in past centuries. Fire intensity has increased on both of these sites, apparently surpassing the past fire-intensity range, because of fuel buildup and "ladder" fuels enabling surface fires to move into the canopy.

As in the ponderosa pine series, increases in tree density together with grazing have contributed to the decline in understory production. Frequent fires consumed forage to the ground, but rhizomatous pinegrass and elk sedge were able to recover quickly. These two species were preferred by cattle and declined with overgrazing (Hall 1975). In Idaho, pinegrass production in grazed stands was only 28 percent of that in ungrazed stands (Zimmerman and Neuenschwander 1984). Conifer regeneration has been encouraged by the decline in competition from rhizomatous species and disruption of the ground by hooves.

In cool, moist plant associations of the grand fir series, with moderate severity fire regimes, the proportion of low severity fire has declined on areas burned over the last century. Small, low-intensity fires have been effectively controlled. The only fires capable of affecting a landscape are those burning under severe weather where fire suppression efforts have failed. Historically, fire created a complex mosaic of underburns where little regeneration was initiated, low-thinned stands (that is, thinning from below with smallest stems being killed) with large residuals where both shade-tolerant and shade-intolerant species could establish, and stand-replacement patches where shade-intolerant species were best adapted. With each type of fire, seral species were favored and dominance of shade-tolerant species was checked. High-severity fires now dominate in this portion of the grand fir series. This shift is from a complex, moderate fire-severity regime to one of high fire-severity.

The lodgepole pine series—This ecosystem is one of the few in which modern human management activities appear to have neither detectable nor actual effects. Overharvest of trees has not generally been a problem, because much of this terrain does not have commercial forest potential. Grazing has not been a problem because not enough forage is produced to make the sites grazable. Fuels have not built up to any great deal, again because of low productivity.

The western hemlock and western redcedar series—Significant effects on these two series from management activities are difficult to detect, although they may be present. In northern Idaho, where these series are widely distributed, the typical fire return interval of 50 to 100 years or more is close to the effective fire-exclusion time. Unlike drier forest types that burned frequently in the past, many of these sites would not have burned even in the absence of fire suppression activities.

A different pattern may exist to the south of Interstate 90, where this type is more of a riparian or valley bottom type. Adjacent forest types, which burn frequently, are more likely to have fires of higher intensity because of fuel buildup, which are likely to move through the riparian forests because of the additional potential for energy release. Although no documentation exists, I suspect a higher proportion of fires in these riparian sites are expected to be more severe than if slope forests had been allowed to burn more frequently.

The subalpine fir and mountain hemlock series—During the past century, high-elevation forest types have experienced the least significant changes of any eastside forest type. A fire-exclusion policy has been in effect for almost a century, but this hasn't dramatically altered these forest types because their naturally long fire return intervals produces little noticeable change in these ecosystems at the stand scale. At the landscape scale, the absence of fire has probably resulted in a slight shift towards later seral communities and away from earlier seral communities. In the Eagle Cap Wilderness of the Blue Mountains, Cole (1981) suggested that valley bottom and lower slope plant associations had the most pronounced floristic response to fire suppression and had more subalpine fir in the understory than the overstory. Fires have not been erased from the landscape in these plant series, however, as shown by the upper portion of the 1960 Anthony Lakes burn on the Wallowa-Whitman National Forest, the White Mountain Complex on the Okanogan National Forest, and other subalpine locations. Sheep grazing in summer occurred in middle to high elevation meadows and ridgelines were favored as driveways to herd the sheep to summer range. Ridgelines may show, therefore, the most significant effects of management activities in forested subalpine zone.

Whitebark pine increases in importance in subalpine areas east of the Cascades crest, occupying 10-15 percent of the landscape. Whitebark pine is a seral species on about half of this area (Arno 1986), and subalpine fir is increasing in importance as the pine is killed by beetles, white pine blister rust (*Cronartium ribicola* Fisch.) and shading from the colonizing fir (Morgan and Bunting 1990). Increased use of fire may not help whitebark pine, even though it may kill back the subalpine fir. Young pines are more susceptible to blister rust infection on the bole, which kills the tree.

Riparian areas—Some riparian areas are surrounded by more continuous and greater accumulations of fuels than in the past. Some ecological changes may be defined in terms of increased risk of wildfire rather than an observed change. For example, the relict population of Alaska-cedar in the Cedar Grove Botani-

cal Area on the Malheur National Forest is a very small riparian grove surrounded by a somewhat drier forest type. The grove has historically been a riparian stringer largely unaffected by the fires burning to its margins, although it has survived one fire this century. With fuel buildups in the bordering forests, the next fire regime may be of higher severity. The grove is now at risk from stand-replacement fires that are likely to occur in neighboring forests. A high-intensity fire could eliminate the cedar from this site and eliminate the only glacial relict population of Alaska-cedar in the Blue Mountains.

In inland Northwest areas, seral riparian stands included large western larch that survived several light burns but are now slowly dying because of competitive stress. Eventually, these 300 to 600 year-old-trees will be eliminated from riparian zones as a result of fire exclusion.

In unburned watersheds, hydrologic effects associated with management changes over the last century include more water usage by denser vegetation cover and in burned watersheds, hydrologic effects include greater tree mortality in burned areas and changes in amount and timing of water flow and sediment yields. Increases in juniper cover from overgrazing and fire exclusion, for example, have been associated with 50 percent reductions in winter soil-water recharge in sage-steppe ecosystems (Eddleman and Miller 1992).

The effects of fire depend on how much of the watershed burns. If fires are small, effects on downstream riparian zones are likely undetectable. If fires are large, peak flows may increase (Helvey and others 1976), summer discharge may be higher, and probabilities of sedimentation, storage, and movement are higher (McNabb and Swanson 1990). Direct effects of fire tend to decrease in effect from edge to the center of the riparian zone. By contrast, indirect effects will usually be highest in the center of the riparian zone and decrease outward.

Subalpine and alpine meadows—Tree invasion of high mountain meadows has sometimes been linked to fire protection efforts in these areas (Ratliff 1985). Such an invasion, however, may also occur under natural conditions, so identifying causes is difficult. In the Pacific Northwest, three distinct natural patterns of meadow invasion have been documented. The first is a drought-induced tree invasion into snow-dominated meadows, where the shrub dominants are generally heathers (*Phyllodoce* spp.). During the 1920-40 regional drought, substantial invasion occurred in these meadows (Franklin and others 1971). The second pattern is related to fire-created meadows that are being recolonized by trees (Agee and Smith 1984, Henderson 1973). These sites are usually steep, south-facing slopes, and colonization lags substantially (30 to 50 years), with most regeneration occurring during wetter than normal summers. Little (1992) found that, on burned sites, extended growing seasons created by early snowmelt in spring and wetter-than-normal summers is associated with tree establishment. In the east Cascades, both of these patterns may exist, and they may be accompanied by yet a third pattern.

The third pattern of tree invasion is associated with wet meadows that have been overgrazed. During the grazing, tree establishment may have been minimal while herbaceous species composition shifted. For example, while pristine subalpine meadows in the Eagle Cap Wilderness of the Blue Mountains have an average cover of 40 to 75 percent tufted hairgrass and Holm's Rocky Mountain sedge (*Carex scopulorum* Holm), grazed meadows have a 10 to 12 percent cover in these species (Cole 1981). Fringeleaf cinquefoil (*Potentilla flabellifolia* Hook.) is a common dominant forb in the grazed meadows. In the Sierra Nevada, some wet meadows experienced a slow recovery of herbaceous vegetation that resulted in gully formation which in turn precipitated a drop in the water table. Better drainage encouraged invasion of lodgepole pine into the drier meadow edges. Under drought conditions, these meadows have burned, killing the invading pines (DeBenedetti and Parsons 1979), but the invasion continues because it is largely independent of fire. In eastside subalpine sites, lodgepole pine and Engelmann spruce are the most likely invading tree species, but this invasion has not been identified as a major problem in Pacific Northwest wet meadows.

MANAGEMENT ISSUES FOR THE 1990s

The Management Challenge

Ecological changes in eastside forests associated with fire exclusion and other management activities have expanded fire hazard and led to declining forest health—problems almost everyone views as undesirable. The solutions require a better linkage of biological and sociopolitical systems than in the past. Numerous popular articles recognize fire must be returned to the system, which is easier said than done. The past role of fire in eastside ecosystems is not a model for management: fire is a tool, not the rule. Eastside ecosystems are more complex in almost every respect than they were a century ago, with unprecedented changes in tree species composition and structure, fuel buildups, alien species, and insect and pathogen dynamics. Restoring fire to an altered ecosystem is fraught with uncertainty. Will old trees survive restoration fires with massive fuel buildups at their bases? Will alien species, so adept at colonizing disturbed ground, become even more dominant?

Restoration fires would have to burn in a land crisscrossed with square and rectangular ownership boundaries. Few natural boundaries for fire can be so neatly scribed on the landscape. Fires will release smoke from biomass that has been accumulating for decades. Smoke that once drifted harmlessly across the valleys of the Columbia Basin would drift into local smoke-sensitive communities. Applying ecosystem management principles, including those that recognize people as part of the ecosystems, is essential to achieving workable solutions (Agee and Johnson 1988). Adaptive management, including strong monitoring and feedback, is also essential if successful treatments are to be expanded and failed treatments abandoned (Walters 1986).

Several institutional issues clearly emerge as important to management. The first is scale. If fire is to be addressed at the proper landscape scale, drip torches will not do the job—aerial ignition will be necessary. The technology is here, but the local skill at using it needs to be developed. Cooperation not only with other local institutions but also with international institutions, such as Australian fire managers who regularly use aerial ignitions, will be necessary. Expanded networks of fire weather stations critical to developing site-specific fire prescriptions are cheap insurance against expensive and avoidable fire escapes.

Local and regional statutes dealing with land zoning and fire protection will need review—all landowners are part of the solution. The urban-wildland interface exists in the Blue Mountains, Bend, Spokane, and Wenatchee—everywhere people live.

Fire management is a more complex job than fire prevention and suppression. Smokey Bear can't say it all in one sentence anymore. Posters on fire ecology should become as widely circulated as posters on fire prevention. Smokey could be positively involved in a program to change the public's awareness of fire for eastside forests. Smokey should still be primarily a symbol of fire prevention, but his role has to be more actively integrated with interpreting the use of fire. Otherwise, fire management in eastside ecosystems may not succeed.

The research challenge outlined below assumes that fire is a part of the solution to the eastside forest health crisis. Yet much is still unknown about where and when fire should be used, how often, and for what ends. The research challenge is to periodically redefine the questions and refocus research accordingly.

The Research Challenge

Efforts to create new information through basic and applied research should continue and that information should be transferred to practitioners through education and training programs.

Education and Training—Workshops should be organized soon for three audiences: the interested public, forest managers/resource specialists, and fire managers. Each has a unique need for fire information. The interested public is likely to be most responsive to television, brief lecture series, or one-day

symposia. Topics might include the forest health situation, the natural role of fire, or how fire can be integrated with community goals.

The second group might include members of interdisciplinary planning teams and decision-makers in charge of selecting management alternatives. These professionals will be evaluating the effects of actions on combined resources and need to have specific information—for example, what fire history information is and how it is collected, techniques of managing fuel consumption, effects of fire on soils and wildlife, and so on. The more details, the better for this audience.

The third audience is the fire manager, the people who will be on the ground applying fire. This group will need even more specifics on fire planning and operations—for example, ignition strategies, fire applications of geographic information systems, biomass consumption prescriptions, and fire weather forecasting, fire danger rating.

Waiting to begin until more research is done is not necessary. Training would improve fire planning efforts and community acceptance and trust before the first research project is completed. Continued technology transfer is certainly recommended, but initial efforts could and should begin soon.

Fire Research—There are a number of topical research areas of high priority where increased information will be essential to adequately plan fire management strategies: Natural fire regimes, effects of global change, vegetation and soil effects, wildlife habitat, visual quality, and effects on cultural resources. More research is needed on variation in regimes and landscape patterns caused by fire. In particular, variation in fire return intervals within a forest series by province or ecoregion is not well documented, and the extent of past fires is largely unknown. Landscape analyses of fire regimes from sagebrush-steppe to alpine zones would be helpful in determining patterns of common scale and severity associated with past fires and the degree to which vegetation-type boundaries acted as fire boundaries. Research projects in oak and juniper woodlands, ponderosa pine, mixed-conifer, and subalpine fir forests, if geographically integrated, could provide a broad understanding of subregional fire histories and yield important information that would have great value in designing restorative fire treatments for landscapes.

Global change scenarios for the Pacific Northwest suggest major shifts in vegetation types. It has been proposed that the shifts will be triggered by landscape disturbances such as timber harvesting or fire (Franklin and others 1991). Climate can be linked to forest fire history and may suggest likely future scenarios with climate change. Some dendroclimatic reconstructions exist for the region (Keen 1937, Graumlich 1987). These reconstructions can be integrated with new information including global change scenarios, to associate climate more closely with what research can tell us about the extent and intensity of past fire.

All ecosystem components will be affected by fire. The focus of research described below is on ecosystem components likely to be significant constraints or opportunities in management plans.

Biomass estimates of major vegetation types are necessary to accurately predict consumption from fire. In particular, relative proportions of live to dead biomass will differ by forest type and by disease and insect hazard category (see Hessburg, appendix A, 1993). Effects of fire on plants is critical if fire prescriptions are to predict the effect of fire on plants based on fireline intensity, season, and ecosystem condition. Examples include effect of intensity and season on bunchgrasses, on aliens such as cheatgrass and knap-weeds (*Centaurea* spp.), on juniper (whether or not the juniper is felled before burning), and on ponderosa pines that have substantial fuel buildup at their bases.

Few studies outside of the southeastern United States have looked at the effects of repeated burns. Current studies (for example, Swezy and Agee 1991) measure the effect of only the first restoration fire, which is likely a maximum effect that would not be repeated in subsequent burns. Consequently, more studies are needed on the effects of repeated burns on all vegetation types.

Research in physical, chemical, and biological soil effects will be necessary as restorative fire treatments are proposed. Landscape erosion studies, that tie slope processes to stream inputs are most important. An obvious link to riparian studies is present. Soil chemistry investigations should focus on the fate of nutrients, such as sulfur and nitrogen that are volatilized by fire, with some attention to nutrients that are transformed to a soluble state in which they may be leached from the system. The magnitude of these effects is a function of fire intensity (Klock and Grier 1979). Long-term productivity of ecosystems may depend on the ability of nitrogen fixing plants to replace nitrogen. Sulfur may continue to be a limiting nutrient, particularly in volcanic soils. Effects of fire on biological properties of soils has been undervalued in the past; mycorrhizae and mesofaunal interactions with fire may be very important for tree regeneration, soil development, and nutrient cycling in the moderate and high-severity fire regimes.

Fire indirectly affects food, cover, and water for wildlife, but direct effects are very minor. Increased use of fire will generally increase water availability to wildlife where it has been a limiting factor, particularly in drier environments. This also has a tie to riparian issues because of potentially increased water flows. Both thermal and hiding cover are likely to be reduced for deer and elk regardless of what is done with managed fire because excessive live-tree density appears to be nonsustainable with or without fire. One important facet will be the value over time of dead understory, created by fire or insect mortality, as hiding or thermal cover. In general, fire will increase summer range forage, but winter range food, such as shrubs, may decrease in cover but have improved palatability. Analyses of the needs of critical wildlife species will be important.

Air quality is the major constraint to fire use in eastside forests, as it is elsewhere. Particulate emissions generated by fire is the most important air-quality parameter when assessing visibility reduction and potential health risks to the public and to fire managers (Sandberg and Dost 1990). Biomass inventories should be tied to emission factors by vegetation type and fuel moisture.

Fire effects on the landscape have been documented in Douglas-fir and ponderosa pine ecosystems in other regions. Effects of fire and other manipulations on the visual quality of specific landscapes can be simulated by computer modelling. This effort needs to be extended to the grand fir series in moderate severity fire regimes and perhaps to western juniper and oak woodlands.

Eastside forests contain tens of thousands of cultural sites and artifacts, some of which may be at risk with increased fire use. More cultural resource inventories will be needed to project potential effects of fire on cultural sites and artifacts.

CONCLUSIONS

Fire was a frequent visitor to eastside ecosystems in the past, and will be in the future. Unlike the inability to predict or mimic some disturbances, people can choose, to some extent, the kind of relation they will have with fire. Past management decisions did not consider or foresee future effects of fire exclusion or fire use. Future choices should be based on the idea that natural resources management is a grand experiment, but not one that has to be unpredictable.

This experiment is grand not only in concept but in scale. If fire were to be reintroduced on a 15-year rotation to ponderosa pine ecosystems and on a 30-year rotation to mixed-conifer ecosystems, about 335,000 ha per year would need to be burned! This area is more than the eastside area now burned with managed fire, much of which is pile burned.

We will have to make better use of available prediction tools, and develop new ones. Considering ecological relations by climax series and plant association groups is useful in understanding major processes and effects, and how each of them varies. Ultimately, insect, disease, and fire hazards should be understood by climax series and these same or similar plant association groups. Landscape ecology organizes and integrates information about fire and other ecosystem components and processes. Increasing and applying this information to eastside ecosystems will ensure their sustained productivity in the broadest biological and social context.

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Ecological Health of River Basins in Forested Regions of Eastern Washington and Oregon

by

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ABSTRACT

A retrospective examination of the history of the cumulative influences of past land and water uses on the ecological health of select river basins in forest regions of eastern Washington and Oregon indicates the loss of fish and riparian habitat diversity and quality since the 19th century. A physiographic framework of the eastern Washington and Oregon in terms of spatial and temporal geologic, climatic and hydrologic conditions provides a regional perspective for reviewing influences of human patterns of settlement, resource development and management on the river basins. The study focuses on impacts of timber harvest, fire management, livestock grazing, mining and irrigation management practices on stream and riparian ecosystems. Extensive reviews of ecosystem damage and fish losses caused by hydroelectric and large irrigation projects, highway and railroad construction and other factors are beyond the scope of this analysis but are summarized. Case histories of the chronology of natural resource uses and health of select river basins, the Okanogan, Methow and Little Naches River basins (Cascade Mountains of Washington) and the Grande Ronde and John Day River basins (northeastern and central Oregon) show that during European settlement period livestock grazing, mining, and irrigation developments were the major land and water uses impacting streams and riparian ecosystems. After the 1940s, timber harvest, road construction and irrigation were the major management impacts. The examination of past environmental management approaches for assessing stream, riparian, and watershed conditions in forest regions shows numerous advantages and shortcomings. The select management approaches include: instream flow incremental methodology (IFIM) for the evaluation of the effect of water diversion on stream flows and salmonid habitats; the equivalent clear-cut method (ECA) for assessing the hydrologic effects of logging; a watershed cumulative effects model (KWCEA) for evaluating the effects of logging and roads on soil loss; and procedures for addressing soil compaction problems. The study concludes by providing recommendations for ecosystem management with emphasis on monitoring and restoration activities.

INTRODUCTION

This document reviews cumulative influences of past land and water uses on the ecological health of select river basins in eastern Washington and Oregon. The first section presents a physiographic framework of eastern Washington and Oregon in terms of spatial and temporal geologic, climatic, and hydrologic conditions. It provides a regional perspective for reviewing the influences of human patterns of settlement, resource development, and management on the health of river basins. The next section is a brief regional overview of land and water uses and their effects on stream and riparian ecosystems, focusing on management practices related to timber harvest, fire management, livestock grazing, mining, and irrigation, although damage to stream and riparian ecosystems and fish losses are caused by other factors—such as hydroelectric and large irrigation projects, highway and railroad construction, agriculture and forest chemicals, recreational activities and management, flood control, dam passage mortalities of fish, and fish lost to mixed-stock ocean fisheries—these considerations are beyond the scope of this analysis and are acknowledged only with key references.

The regional overview sets the stage for more-detailed case histories for select river basins of the region. The case histories focus on the chronology of natural resource uses and health of select river basins in eastern Washington and Oregon: the Okanogan and Methow River basins (north-central Washington), the Little Naches River of the Yakima River drainage in the eastern Cascade Mountains, the Grande Ronde River basin (Blue Mountains of eastern Oregon), and The John Day River basin in north-central Oregon. The history of the Okanogan and Methow River basins focuses on the chronology of events during the last century and the early 1900s that shaped current landscapes and socioeconomic conditions in eastern Washington and Oregon. Summaries of the histories for the Little Naches, Grande Ronde, and John Day River basins provide more-specific reviews of land and water uses that have influenced stream and riparian ecosystems in these river basin landscapes.

The next section reviews select management approaches that have been used to improve and protect watershed, stream, and riparian ecosystems. The review includes select applications of the instream-flow incremental methodology (IFIM) for evaluating the effect of water diversion on stream flows and salmonid habitats (Methow River, WA); the equivalent clearcut method (ECA) for assessing the hydrologic effects of logging; a watershed cumulative effects model (KWCEA) for evaluating the effects of logging and roads on soil loss; and procedures for addressing soil compaction problems.

The concluding section provides recommendations for ecosystem management. The recommendations focus on developing perspectives of river basin or landscape management with emphasis on monitoring and restoration activities. We acknowledge ongoing reports that are developing various action plans for restoring and maintaining watersheds and stream and riparian ecosystems in the Columbia River basin.

Sources of information that complement this document directly include papers by McIntosh and others (1993) and USDA Forest Services PACFISH Strategy, (in press). The review by McIntosh and others (1993) focuses on how stream habitats of salmon have changed in tributaries of the Methow, Wenatchee, Yakima, and Grand Ronde River basins over the past 50 years. Management concepts and recommendations being incorporated into the PACFISH Strategy reflect those developed in the Upper Grande Ronde River Anadromous Fish Habitat Protection, Restoration, and Monitoring Plan (Anderson 1992).

EASTERN WASHINGTON AND OREGON PHYSIOGRAPHY

Geological Landforms

Eastern Washington and Oregon have four general physiographic areas (table 1), each differing from the others in climate, topography, and natural resources. These conditions, along with the unique geology, have broad influences on the ecology of a natural ecosystem and human economy. The major landforms in the eastern part of the State include the Northeastern Highlands or Okanogan Highlands, the Columbia Plateau, the Blue Mountains, and the Cascade Range. These landforms began to develop about 200 million years B.P. (before the present).

Table 1—Geologic landforms of eastern Washington and Oregon*.

-
- | |
|---|
| 1) Northeastern Highlands or Okanogan Highlands |
| 2) Columbia Plateau |
| 3) Blue Mountains |
| 4) Cascade Mountains |
| North Cascade Subcontinent |
| Cascade Volcanoes |
-

*Alt, D.D. and D.W. Hyndman (1984)

The drifting movement of the North American continent during the early Mesozoic Era initiated the formation of geologic regions in the Pacific Northwest (Alt and Hyndman 1984). Two hundred million years ago, the North American continent began to move away from Europe. As North America moved west, the floor of the Pacific Ocean began slipping below the westward moving continent and disappearing into the mantle. The collision of North America with the ocean floor crushed the old coastal plain into a belt of tightly folded sedimentary rock. This belt of folded rock, the Kootenay Arc, extends through eastern Washington and British Columbia. The Kootenay Arc disappears beneath younger rock west of Spokane. The Blue Mountains and the Wallowa Mountains of Oregon may be the southward continuation of the Kootenay Arc.

As North America moved west, it collided with small island continents, forming other distinct geologic regions. The first addition, the Okanogan Subcontinent, formed about 100 million years ago (late Mesozoic-early Cenozoic Era) and is now the high land between the Columbia and Okanogan Rivers. Afterwards North America was still moving west and the Okanogan Trench, in the vicinity of the Okanogan valley, formed where the ocean floor collided with the Okanogan Subcontinent.

Fifty million years ago during the Tertiary period, the North Cascade Subcontinent collided with North America and obliterated the Okanogan Trench just west of the Okanogan Valley. The North Cascade Subcontinent contained active volcanoes that lasted until 25 million years ago. For the next 10 to 15 million years, the Cascade volcanic activity subsided. The focus of volcanic activity shifted east to form the Columbia Plateau (black basalt lava flows). After this period the activity shifted back to the Cascade to form the high Cascade Range.

Climate Change and the Development of River Drainages

As the Columbia Plateau was being built by eruptions, the Pacific Northwest appeared to have a wet tropical climate. When the eruptions subsided, the climate became dry (Pliocene Epoch, 8 to 30 million years ago). About 2 to 3 million years ago, the Earth's climate became unstable. Since that time, the Pleistocene epoch (duration of ~10,000 to 2 million years B.P.) experienced several ice ages (Dunne and Leopold 1978). During the last two ice ages, large glaciers covered most of the northern two thirds of Washington as well as the higher mountains. Glaciers left morainal ridges and expanses of outwashes. Moraines were formed of till consisting of fragments ranging from clay to boulders. Outwashes were formed by torrential flows of summer meltwater that transported large amounts of sediments off the ice to form gravel and sand deposits below moraines.

Glaciation during the Pleistocene played a significant role in forming many river basins in north Washington. For example, before glaciation, the Columbia River flowed across rather than around what is now the Colville Indian Reservation. In the vicinity of Omak, the river flowed through what are now Big Goose Lake and Omak Lake, then turned south following the present course of the Okanogan River. A glacier formed in the Okanogan valley and blocked this passage, forcing the Columbia into its present course and leaving Omak Lake. Later advances of glacial lobes also blocked the Columbia River causing the river to carve out the Grand Coulee (Wilson 1990).

The North Cascades were glaciated by alpine glaciers before the continental ice sheet, which covered all but the highest mountains in both the North Cascades and the Okanogan Highlands. The continental ice did not greatly alter the basic shapes of alpine glaciated landforms (cirques, pointed peaks, and U-shaped valleys between steep, highly dissected ridges) of the North Cascades but removed most depositional material left by the alpine glaciers. In contrast, in the Okanogan Highlands, where alpine glaciation did not precede the continental ice sheet, landforms were smoothed, leaving moderate slopes and broad rounded summits (Williams and Lillybridge 1983).

During the Pleistocene, the landscape geomorphology of eastern Washington landscape was altered by large, catastrophic floods. Large ice dams and lakes formed by glaciers were breached, releasing massive volumes of water. The largest flood, the Spokane flood, occurred when the ice dam of Glacial Lake Missoula in western Montana broke and released 2500 km³ of water into eastern Washington, forming channeled scapelands, as well as altering the Columbia River's mainstream channel (Baker and others 1987). The chronology of other geologic, geomorphic, and climate factors influencing eastern Washington and Oregon landscapes since the Pliocene are summarized in table 2.

Table 2—Chronology of geologic, geomorphic and climate factors influencing eastern Washington and Oregon landscapes since the Pliocene Epoch. Modified from ERDA 1979.

EPOCH	Age Years BP	Geologic Units	Geologic and Related Events	Climatic Trends
HOLOCENE	Modern	Landslides	Hydrologic induced landsliding	Cooler, moister
	4,000	Ash deposits	Eruption of Mt. St. Helens	
		Palouse soils & dunes	Dune creation, little mass wasting	
			Columbia River at low flow	
	6,000	Ash deposits	Eruption of Mt. Mazama	Warmer & drier
	8,000	Eolian sediments	Extinction of many large mammals, early man known in basin	
	10,000	Landslides	Floods & landslides	
	12,000	Ash deposits	Eruption of Glacier Peak	
PLEISTOCENE		Flood deposits	Continued anticlinal uplift & basining, floods, grazing animals in region	Onset of ice age
	18,000 22,000	Flood deposits & erosion	Catastrophic floods from Glacial Lake Missoula, extensive erosion, landsliding and sediment deposition	
	50,000	Early flood deposits	Glacial ice dams breach & flood	
	1 - 2 Million			

Studies of the Holocene epoch (duration of modern to ~10,000 years B.P.) have provided insight into the effect of climate changes on riverine ecosystems. During the middle Holocene, the Hypsithermal interval of 6000 to 9000 years B.P. provides a model of the effects of future warming temperatures on river ecosystems of the Pacific Northwest region (Chatters and others 1991). For the region, the Hypsithermal interval appeared to have temperatures averaging 1 to 2° C warmer and 33 to 38 percent drier than today. Timber-lines in the Cascade and Rocky Mountains were between 150 and 300 m higher during the middle Holocene than they are now (Osborn and Luckman 1988). Reconstruction of prehistoric stream conditions from floodplain deposits and fossil mussel shells, and from moisture estimates from pollen data, suggests stream flows approached 33 percent less than today. The warm water, the reduction in stream flows, altered stream hydrographs, and finer stream substrates conditions of the mid-Holocene may have been common for riverine ecosystems throughout the Columbia River basin. If such conditions existed today, perennial streams might be intermittent, the warmer waters uninhabitable by salmonids. The reconstruction of mid-Holocene climate suggests how future climate warming periods might influence stream ecosystems. For example, a Hypsithermal interval and drier climates combined with today's depressed salmon populations could further reduce fish abundance. Such conditions might also increase evaporation, and reduce forest and riparian cover, and surface runoff (Chatters and others 1991, Neitzel and others 1991).

Ecoregions and Hydrology

Ecoregions—Landscapes that contain river drainage basins and their tributary watersheds can be described by a hierarchy that places ecoregions at the largest spatial scale. Nested within ecoregions are geomorphic components of decreasing size. They include river basins, tributary watersheds, and stream and riparian habitats. Ecoregions have been defined as areas of relative homogeneity in ecological systems (Hughes and others 1990, Omernik 1987) and their components such as forests, soils, and fish and wildlife assemblages and distributions, as well as relations with hydrologic, climatic, geological conditions, and fire regimes. Some of the most pronounced differences occur between "arid" ecoregions of eastern Washington and Oregon and ecoregions of high rainfall near the eastern crest and west of the Cascade Range. Six ecoregions occur in eastern Washington and Oregon. River basins in arid ecoregions commonly have dominant contributions of discharge in headwaters and minimal downstream water sources. In contrast, drainages in high rainfall ecoregions commonly have significant contributions of discharge both in headwater and downstream portions of a river basin.

Depending on geological formations, such as basalt bedrock and glacial alluvium, rivers in mountain valleys of many eastside ecoregions can exhibit shallow to deeply entrenched channels. Although the geology relative to hardness and permeability is highly variable, fluvial geomorphic processes of erosion and deposition also contribute to many large-scale morphological characteristics of the drainage basins. Although lithology can provide bedrock channels in deep and narrow valleys, erosion and deposition produce semiconfined and unconfined channels in alluvial valleys and broad floodplains (Rosgen 1985, Schumm 1985). Geologic and geomorphic features of headwater tributary watersheds, such as streambank failures and landslides from hillslopes, usually control modes of delivery of debris to stream and riparian habitats, as well as influence the type and size of sediment supplied to downstream valleys (Baker and others 1988). Factors like hillslope relief, stream channel drainages, density characteristics of watersheds, climatic conditions, and peak flow events influence cumulative effects of material delivery and transport (Horton 1945, Parker 1977, Patton 1988).

Hydrologic and climatic characteristics—More than 75 percent of the continental U.S. water supply has its origin on forested lands. In Washington and Oregon, more than 95 percent of usable streamflow can come from forested and alpine lands. Washington and Oregon can be stratified into major hydrologic regimes based on precipitation as rain and snow and average winter temperatures. Major topographic features of mountain ranges and marine influences, such as oceanic currents, create climates that yield definite hydrologic regimes and patterns of vegetation. These interactions influence the development and location of agricultural, industrial, and urban centers.

Climate—Coastal river basins in warm maritime-subclimatic zones along the North Pacific coast have flow patterns characterized by rainfall-induced floods in fall and winter. Such river basins are usually short, originating in mountainous coastal regions. These river basins can have distinct subclimates because of interactions between atmospheric circulation patterns and abrupt coastal mountains that serve as barriers to the movement of air masses. The basins have west-facing mountains with dense clouds and high precipitation.

Warm coastal subclimates are a result of the coastal climate being largely controlled by macro-scale atmospheric processes (Thomas 1977). The usual circulation pattern during the winter is produced by a strong temperature gradient between tropical and polar latitudes. Winter low pressures over the Gulf of Alaska and high pressures on the continent combine to produce strong pressure gradients on the North Pacific coast where southerly surface winds prevail. As a result, numerous storms develop rapidly over the Pacific Ocean, with small-scale frontal systems breaking away from storm centers and impinging on the coast. These fronts bring the strong southwesterly flows of warm air that are responsible for coastal rainfalls. Summer atmospheric circulation patterns are weaker, being controlled by a large high pressure center over the north Pacific Ocean and coast. The result is weaker pressure gradients, northwesterly winds, and low frequency and intensity of Pacific storms.

Variations in precipitation, when frontal systems impinge on diverse landscapes for different river basins in the Pacific Northwest, are caused by circulation patterns and interactions with local topographic features such as elevation, slope, and aspect. These characteristics are reflected in the different flood regimes of river basins. For example, extreme floods do not result from the same flood-producing mechanisms on all drainage basins. River basins west of the Cascades can have rainfall-induced flood regimes, either as rainfall runoff only, or as rain-on-snow runoff in fall and winter; other watersheds both west and east of the Cascades have snowmelt-induced flood regimes in spring or summer. Some western basins can have both rainfall-induced and rain-on-snow flood regimes. Eastern Washington and Oregon drainages feature snowmelt-induced flood regimes (spring/summer) typical of cold interior or continental regions (Melone 1985). Select river basins east of the Cascade can sometimes be influenced by rain-on-snow runoff events.

Hydrologic regions—River basins of eastern Washington and Oregon can be grouped by major hydrologic regions, based on precipitation inputs and average winter temperatures (table 3). This approach is based on the dominance of the maritime climatic patterns and interactions of climate and topographic features with inland landforms, which form definite hydrologic zones and distinct snow accumulation patterns (Wooldridge 1972). The hydrologic regions include the Blue Mountains Basins, The Great Basin, Columbia Plateau Basins, Columbia South Cascade Basins, Columbia North Cascade Basins, and the Northcentral and Eastern Upland Basins (table 3). All the rivers are tributaries to the Columbia River, the major source of water in Washington and Oregon.

Table 3—Major hydrologic regions and rivers in eastern Washington and Oregon.*

Blue Mountains Basins

Grande Ronde River, OR
John Day River, OR
Powder River, OR
Malheur River, OR

Great Basin

Owyhee River, OR

Columbia Plateau Basins

Snake River, WA and OR
Crab Creek, WA

Columbia South Cascades Basins

Deschutes River, OR
Yakima River, WA

Columbia North Cascades Basins

Methow River, WA
Chelan River, WA
Wenatchee River, WA

Northcentral and eastern Upland Basins

Okanogan River, WA
Kettle River, WA
Colville River, WA
Pend Oreille Rivers

*Modified after Wooldridge (1972) and Highsmith and Kimerling (1979).

Snow accumulation patterns and streamflows—The concept of hydrologic regimes being controlled by the form of precipitation released for streamflow can be studied by examining snow accumulation zones. Once the water reaches the Earth's surface, hydrologic regimes are influenced by basin characteristics such as topography, relief, length, stream gradient, vegetation, and soils. In mountainous regions, the most obvious and dominant influences are elevational and orographic features. These factors have considerable influence on the source and timing of streamflow.

Three general snow zones exist in Washington: the No Snow Zone, the Warm Snow Zone, and the Cold Snow zone. The No Snow Zone includes the coastal and Puget Sound lowlands. The coastal lowlands cover areas below 2000 ft along the Pacific Ocean. Summers are cool and humid with temperatures averaging 55° F and little rainfall. Precipitation averages 90 in/year below 2000 ft and over 150 in/year above 2000 ft. Most of the rainfall (50 percent) occurs during November, December, and January. Snow accumulates above 2000 ft in the interior mountains. Hydrologic regimes in the No Snow Zones have their highest flows during the wettest month of January because of vigorous winter rainstorms. The Puget Sound lowland's climate is moderated by Puget Sound and forms a boundary with the Warm Snow Zone. Winter temperatures range in the 30 to 40's and in the summer exceed 60° F. Intermittent snow falls below 2000 ft, and continuous snow cover usually exists above 2000 ft, varying with topography and solar radiation. Small drainage basins usually show rapid response to rainfall. Very low flows occur in the dry months of July, August, and September. Orographic influences are common throughout the year, increasing during late summer to a maximum in November. Very high winter rains during December, January, and February may negate orographic effects of elevation.

The Warm Snow Zone extends from the rainfall zone to 5000 feet in the Cascades Range but higher in the Olympic Mountains. Snow cover can occur from October to March. Deep snow accumulations from 5 to 20 feet can occur in the Cascades, with records near Paradise, Mount Rainier. This zone can spill over to the eastside of the Cascades. Intermittent Warm Snow Zones may develop, where orographic conditions permit, in mountainous areas in the Colville National Forest of northern Washington and the Idaho Panhandle. Warm air masses of 50 to 60° F can occur for a few days in winter and are usually accompanied by moderate to heavy rainfall. Under these conditions, the warm snowpack, which is usually isothermal, can respond rapidly to significant rainfall because the snowpack transmits water in a manner similar to the soil matrix. The result can be significant flooding events during periods of rain or warm air mass movement. The effects of the warm snow zone on streamflow vary with topography, timberline, glaciation, soil depth, and forest conditions.

The Cold Snow Zone occurs above 5000 feet in the western Cascades and in eastern Washington and Oregon. Temperatures below freezing result in continuous snow accumulation as a cold snowpack. Precipitation follows maritime patterns but most of the streamflow occurs during the annual melt of May, June, and July. The Cold Snow Zone can be subdivided into a high precipitation zone of the high Cascades (> 5000 ft with > 50 in/year with extended snow cover periods) and a low precipitation zone (10 to 15 in/year) at lower elevations east of the Cascades. In eastern Washington and Oregon, elevations below 2000 ft usually do not contribute significantly to streamflows. The transition zone between the ponderosa pine forests and the brush-grassland vegetation types is at 1500 to 2000 ft elevation. A climatic anomaly to this plant-rainfall association occurs in the Okanogan Highlands. This area receives a large portion of its annual rainfall in the summer allowing commercial forests to grow at lower elevations on drier sites.

The Wenatchee River (eastern Cascades) and Colville River (northeastern Washington) basins are examples of Cold Snow Zone river basins. Rugged-high elevations of the Wenatchee River basin are above timberline, with some glaciers and snowfields. Commercial forests are at lower elevations than the subalpine forests. They consist of mixtures of Douglas-fir, Pacific silver fir, and western hemlock. Ponderosa pine occupy a wide range of transitional elevations. In contrast to the wide elevational zones of the Wenatchee basin, the Colville River basin consists of gently rolling foothills.

In the Wenatchee River basin, the rain shadow and orographic effects of the Cascades cause low water yields at lower elevations. Variations in run-off patterns are caused by differences in topography and orientation of subbasins. These variations at lower elevations and higher solar-radiation earlier in the year increase contributions of snow melt. These influences can shift flow peaks into April. The Colville River basin is typical of the Cold Snow Zone, with maximum runoff in late spring due to snowmelt. The monthly distribution of runoff is similar to the Wenatchee River.

REGIONAL OVERVIEW

The following sections provide overviews of the status of stream and riparian ecosystems and of the primary effects of land and water uses on these ecosystems in river basins of eastern Washington and Oregon. These reviews set the stage for case histories of select river basins of the region. The case histories focus on the chronology of natural resource uses and the health of streams and riparian ecosystems. The river basins include the Okanogan and Methow River (north-central Washington), the Little Naches River of the Yakima River drainage (central Washington), the Grande Ronde River (eastern Oregon), and the John Day River basin in north-central Oregon.

Information about other river basins in eastern Washington and Oregon that complement this document includes the review of the management history of salmonid habitats in eastern Washington and Oregon (McIntosh and others 1993). This review focuses on changes in salmon habitat over 50 years (1935-92) in tributaries of the Grande Ronde, Yakima, Wenatchee, and Methow River basins. Other important

sources of information about the chronologies of major settlement, natural resource uses, and related historical events and developments in eastern Washington and Oregon include Dicken and Dicken (1979), Highsmith and Kimerling (1979), Kerr (1931), Steele (1904), and Wilson (1990), and more local histories of National Forests such as Holstine (1987).

Stream and Riparian Ecosystems

Both historically and today, the landscapes of eastern Washington and Oregon, like most of the Pacific Northwest, contain numerous watershed, stream, and riparian ecosystems that have and are being continuously degraded by a combination of agriculture and irrigation, timber harvest and forest management, road building, livestock grazing, mining, and the combined or cumulative effects (Peterson and others 1992, NCASI 1992) of these and other land- and water-use practices. Examples of significant changes in stream- and riparian-habitat qualities that indicate degraded conditions in different river basins of eastern Washington and Oregon are given below. Major habitat changes include the loss of riparian vegetation and increased canopy opening widths adjacent to stream channels; loss of riparian vegetation and decline of large woody debris in stream channels; increases in water temperatures from minimal shading by riparian canopies and shallow-sediment and debris laden stream channels; accumulation of fine sediments and loss of gravel and pool attributes in stream channels because of land-uses that alter streamflow regimes and sediment budgets; and loss of water in stream channels and riparian areas because of water diversion practices. Much information for eastern Washington and Oregon relates to changes in stream and riparian habitats and responses of salmonids to habitat alteration—changes, for example, in the following: riparian canopy widths (Smith 1993); large woody debris distribution in streams (Bilby and Wasserman 1989); water temperatures (Berman and Quinn 1991, Li and others 1992, Maloney and others, in press); substrate conditions (Chapman 1988, Corner 1992, McIntosh and others 1993, Smith 1993); and water diversion and streamflows (Caldwell and Catterson 1992). A recent synthesis document provides valuable information that focuses exclusively on the past and present conditions of stream habitats and salmonid stocks in the central Columbia River basin of Washington (Mullan and others 1992).

Stream conditions and salmonid stocks—Much of the eastside region that exhibits stream and riparian degradation is found in upland forests and range areas. Major land and water uses affecting these stream and riparian ecosystems include timber harvest practices, fire management, livestock grazing, mining, and irrigation. Although detailed accounts of other human activities altering stream and riparian ecosystems are beyond the scope of this analysis, the following summary describes some important modifications of these ecosystems and related responses of ecologically sensitive salmonid stocks in eastern Washington and Oregon. These modifications include hydroelectric and large irrigation projects, and dam passage mortalities of salmon and fish lost to mixed-stock ocean fisheries.

During the 1930s and 1940s, permanent blockage of riverine channels by large mainstream dams, such as the Chief Joseph and Grand Coulee dams, assured the loss and degradation of salmon and steelhead habitat. Dams with no feasible fish passage facilities have inundated rivers, destroying rearing and spawning habitats and increasing downstream migration time. Losses in anadromous fish habitat in the Columbia (above Bonneville Dam) and Snake Rivers between 1850 and the present have been estimated at 35 percent, a decrease from about 11,700 to 7600 miles of stream. Cumulative passage mortality for juvenile fish moving downstream to the ocean is estimated to be about 77 to 96 percent and the corresponding mortality for adults moving upstream is 37 to 51 percent (NPPC Staff 1986).

Fish losses in mixed-stock ocean fisheries have been attributed to equal rates of fishing pressure suffered by both upper and lower Columbia River runs, resulting in overfishing of the weaker upriver and wild fish runs. Fish harvest rates are commonly set for the stronger down river runs, which includes runs, below Bonneville Dam. These fish runs are stronger because they have received considerable hatchery supplementation. The Mitchell Act (16 U.S.C. -750) for hatchery programs in 1949 caused downstream river hatchery production in the 1960s to surpass natural production. This extensive production of hatchery fish along with overfishing of wild and upriver runs and permanent blockage by large dams, has led to the

elimination of some fish runs as well as changes in the genetic character of many stocks (NPPC Staff 1986). Additional losses of habitat and runs have occurred throughout the Columbia River basin because of damage and reclamation actions related to forestry, grazing, mining, farming-irrigation, and other practices. Finally, although the environmental problems facing salmon and steelhead are extensive and cumulative, their environmental effects are often confounded by natural biotic interactions including introductions of disease, exotic species, and predators.

Riparian conditions—Riparian ecosystems in eastern Washington and Oregon, as in most climatic regions, reflect interactions between hydrologic and geomorphic processes associated with landforms, terrestrial and aquatic ecosystems, and river basin landscapes. Riparian ecosystems are water dependent systems adjacent to aquatic ecosystems. They contain plant and soil systems with both wetland and upland attributes that provide the vital transition between forest and stream, hillslope and valley, and terrestrial and aquatic ecosystems. Important functions include water movements and the transport of sediments, nutrients, and exotic and toxic materials (Belt and others 1992, DeBano and others 1990, Gregory and others 1991, Leonard and others 1992, Minshall and others 1989, Wissmar and Swanson 1990).

In eastern Washington and Oregon, riparian ecosystems are high-use areas desired by many elements of society for many purposes. Riparian areas are commonly subjected to intensive management practices to promote water conservation and to provide grazing for livestock. Grazing, irrigation, timber harvest, mining, road construction and maintenance, agricultural practices, and high runoff events over the past 100 to 150 years have caused considerable habitat damage and neglect of riparian ecosystems (Beschta and others 1991, Elmore and Beschta 1987, Kauffman 1988, Kauffman and Krueger 1984). Conflicts over control of riparian resources by user groups—water, timber, livestock, wildlife, recreational, and environmental—are intense and cause complex management problems. Hanson (1987) in a report for the Oregon Environmental Council qualitatively identified the most apparent factors contributing to the deterioration of riparian areas in 11 different river basins of eastern Oregon (table 4). The order of importance of the major factors affecting riparian areas appears to be livestock grazing > timber harvest practices > agricultural practices > road construction > flood events. The next section contains a summary of livestock grazing in eastern Washington and Oregon.

Table 4—Summary of the “major factors affecting riparian areas” in the different river basins of eastern Oregon (Hanson 1987).

“Major Factors Affecting Riparian Areas”													
River Basin	Grazing	Logging	Roads	Stream Channelization	Floods	Irrigation	Spraying Chemicals	Mining	Agriculture	Dams	Natural Erosion	Rural Devel.	Recreation
Malheur L.	x	x	x		x	x	x		x				
Malheur R.	x	x	x		x	x		x	x				
Owyhee R.	x				x					x			
Goose & Summer L.	x	x	x								x		
Klamath R.	x	x	x		x				x				
Deschutes R.	x	x		x					x		x	x	x
Hood R.	x	x	x				x		x		x		
John Day R.	x	x	x	x	x	x		x	x				
Umatilla R.	x	x		x	x			x	x				
Grande Ronde R.	x	x	x	x	x			x	x				
Powder R.	x	x						x					

Although minimal information exists about the quantity, types, and conditions of riparian ecosystems in eastern Washington, the U.S.D.A. Forest Service has started inventorying riparian ecosystems associated with grazing allotments (Quigley and others 1989). Preliminary estimates are being made by the Pacific Northwest Region of the Forest Service of the amounts and status of riparian vegetation in grazing allotments of the 10 National Forests of eastern Washington and Oregon. For all 10 Forests, current estimates for acres of range with riparian vegetation and Forest Plan management objectives suggest 4 percent are riparian (399,043 riparian acres). The Forests with the highest percentage of riparian acres were the Winema (11 percent) and Umatilla (6 percent), those with the lowest were the Wallowa-Whitman (1 percent) and the Wenatchee, Deschutes, and Malheur at 2 percent each. Estimates of the total riparian acres in grazing allotments for each National Forest are shown in figure 1.

Estimates of total riparian acres within allotments were partitioned into categories as follows: acres meeting or moving toward Forest Plan objectives; acres not meeting or moving toward Forest Plan objectives; and acres of undetermined status (Quigley and others 1989). For nine of the Forests (no data available for the Wallowa-Whitman), the mean percentages of the total riparian acres (399,043 acres) in these categories were 50 percent meeting or moving toward the objectives, 13 percent not meeting or moving toward the objectives, and 37 percent in the undetermined status. For each Forest, the percentages in these categories are presented in figure 2. The percentage of riparian acres meeting or moving toward the objectives ranged from 22 to 79 percent with the highest values in the Malheur, Deschutes, and Fremont (56 to 59 percent), and in the Ochoco and Colville Forests (78 and 79 percent). Percentages of riparian acres not meeting or moving toward the objectives ranged from 1 to 41 percent with all Forests being less than 10 percent except the Umatilla (20 percent), Fremont (26 percent), and Wenatchee (41 percent). Five of the Forests had riparian acres of undetermined status ranging from 35 to 76 percent, with the highest percentage in the Okanogan (fig. 2). This Forest Service information is preliminary and needs to be further clarified in terms of Forest Plan objectives; definition of riparian acreages and boundaries between terrestrial and riparian systems; and riparian acreages within allotments versus the total riparian acreage for the respective National Forests (Pacific Northwest Region, fiscal year-92 Range Report).

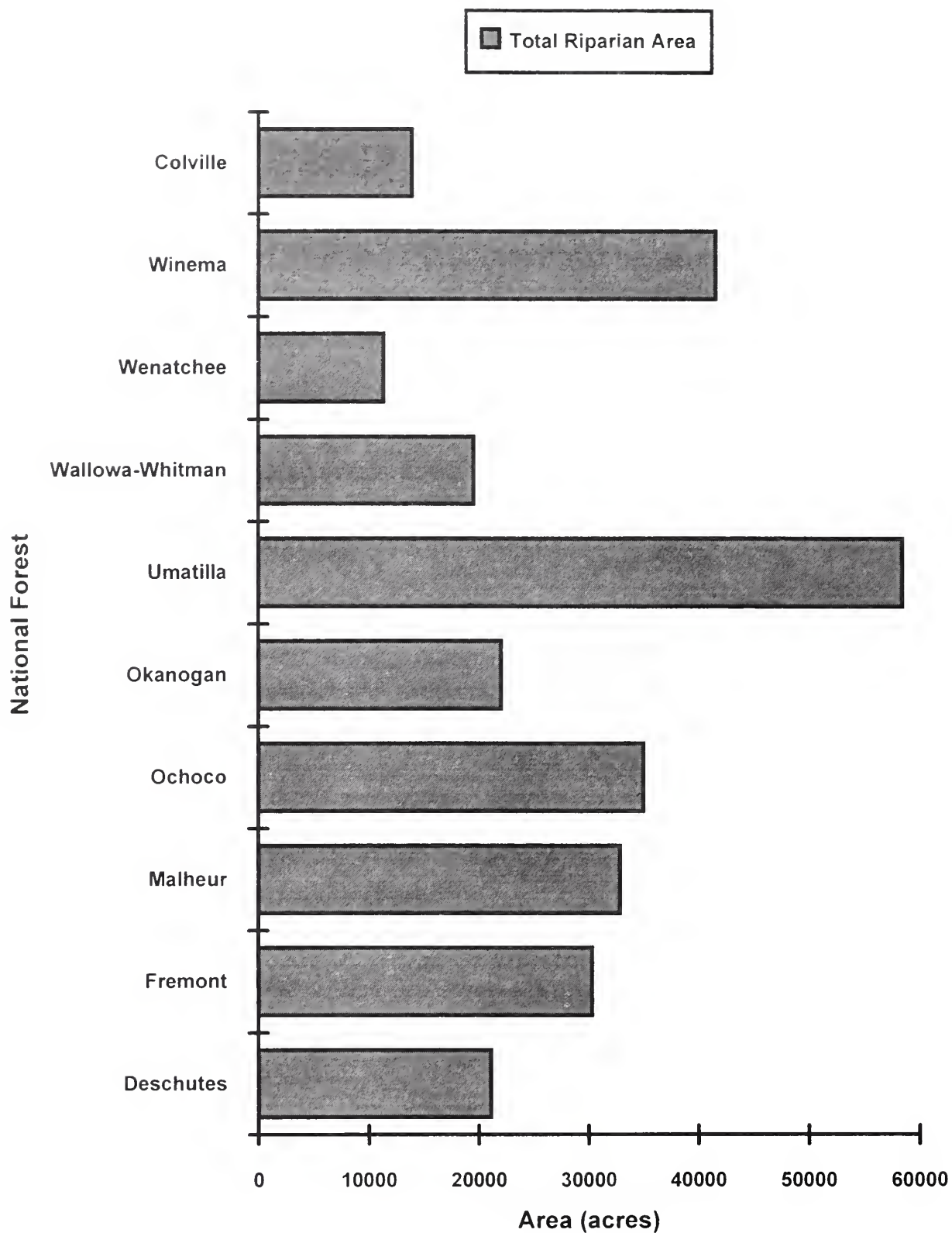


Figure 1. Estimates of total riparian area in grazing allotments of National Forests in eastern Washington and Oregon (Region 6, FY-92 Range Report, Portland, OR).

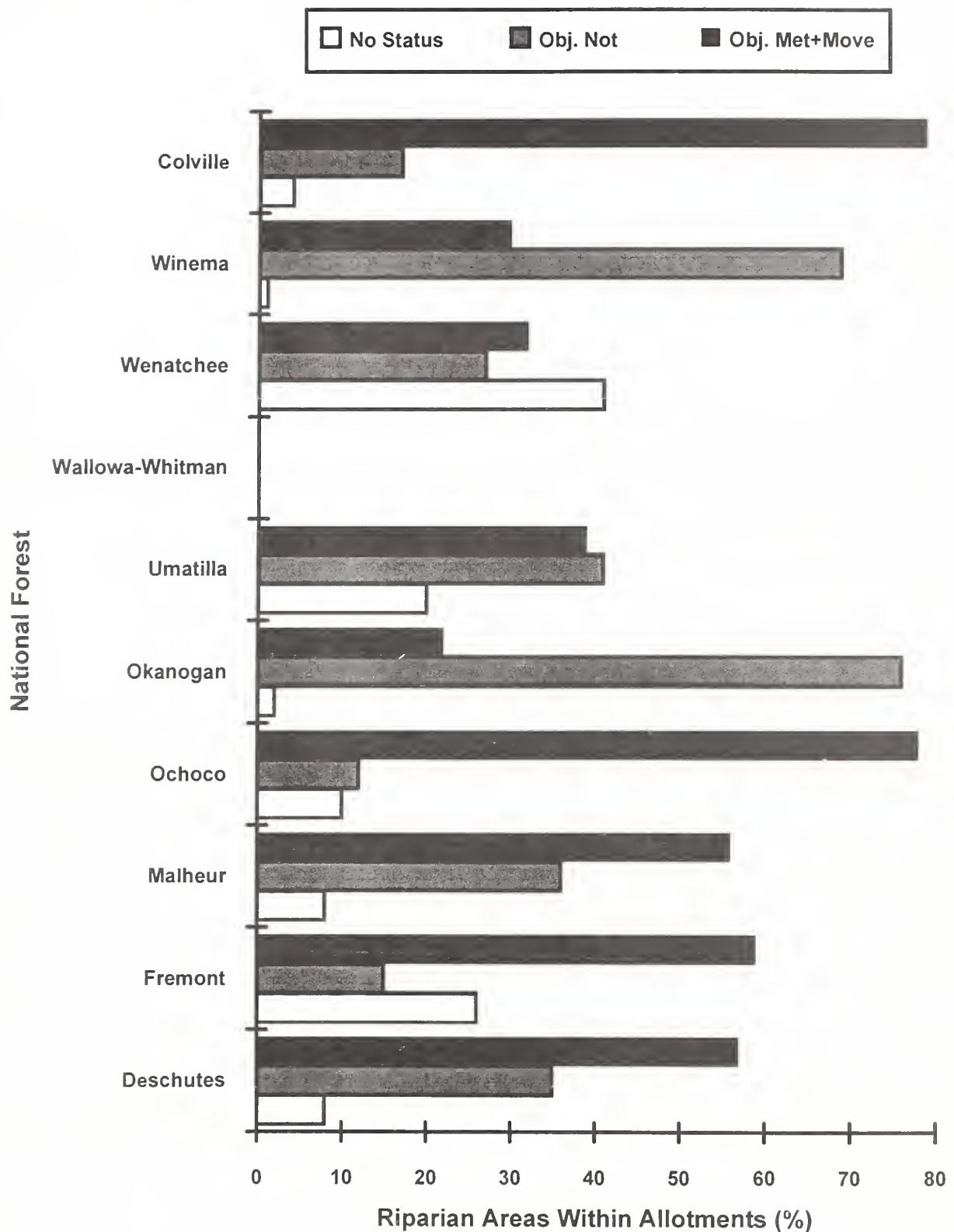


Figure 2. Estimated percentage of total riparian area in grazing allotments for three categories of Forest Plan objectives for National Forests in eastern Washington and Oregon (Region 6, FY-92 Range Report, Portland, OR). The categories include: a) acres meeting or moving toward Forest Plan objectives; b) acres not meeting or moving toward Forest Plan objectives; and c) acres of undetermined status.

Primary Resource Uses Affecting Stream and Riparian Ecosystems

This section summarizes stream and riparian habitat conditions in river basins relating to forest management practices and other land- and water-use effects of fire management, livestock grazing, mining, and irrigation. Stream and riparian ecosystem changes and fish losses caused by other factors are important but beyond the scope of this analysis. These factors include modification of riverine ecosystems by hydroelectric and large irrigation projects, highway and railroad construction (Furniss and others 1991), agriculture and forest chemicals (Norris and others 1991), recreational activities and management (Clark and Gibbons 1991), flood control (R.W. Beck Associates 1973), dam passage mortalities of fish, and fish lost to mixed-stock ocean fisheries. Additional information about the influences of these land- and water-use activities in the Pacific Northwest region on stream and riparian ecosystems can be found in Meehan (1991) and Mullan and others (1992).

Timber harvest and road construction—Numerous studies have documented the history of the effects of timber harvest practices and related transportation systems (such as roads, landings, and skid trails) on watersheds and changes in hillslope stability, water quality, riparian and stream habitat stability, water yield, peak flows, and related conditions (Meehan 1991, NCASI 1992, Peterson and others 1992, Salo and Cundy 1987). During the last century and the early 1900s initial entry into the forests of eastern Washington and Oregon was made through river valleys, riparian areas of floodplains, and adjacent hillslopes. Harvest techniques were a variety of high grading and other select strategies. Early reports indicate minimal rates of harvest until World War II and the next four decades (Oregon Department of Forestry 1985, Plummer 1900, Washington State Department of Natural Resources 1985). Harvest records have been kept by the Forest Service, Washington State Department of Natural Resources, and the Oregon Department of Forestry since about 1925. These records indicate two different patterns of timber harvest in eastern Oregon and Washington (fig. 3). Harvest rates increased dramatically before and after World War II in eastern Oregon and have increased steadily up to the present. In contrast, harvest in eastern Washington has remained at fairly stable rates since 1925, increasing slightly over the past 65 years. Harvest rates in eastern Washington have been about one-third those of eastern Oregon (fig. 3, where total harvest = private + State + Federal). These differences can be partially attributed to about 65 percent of the Forest Service lands in eastern Washington being in Wilderness and roadless condition.

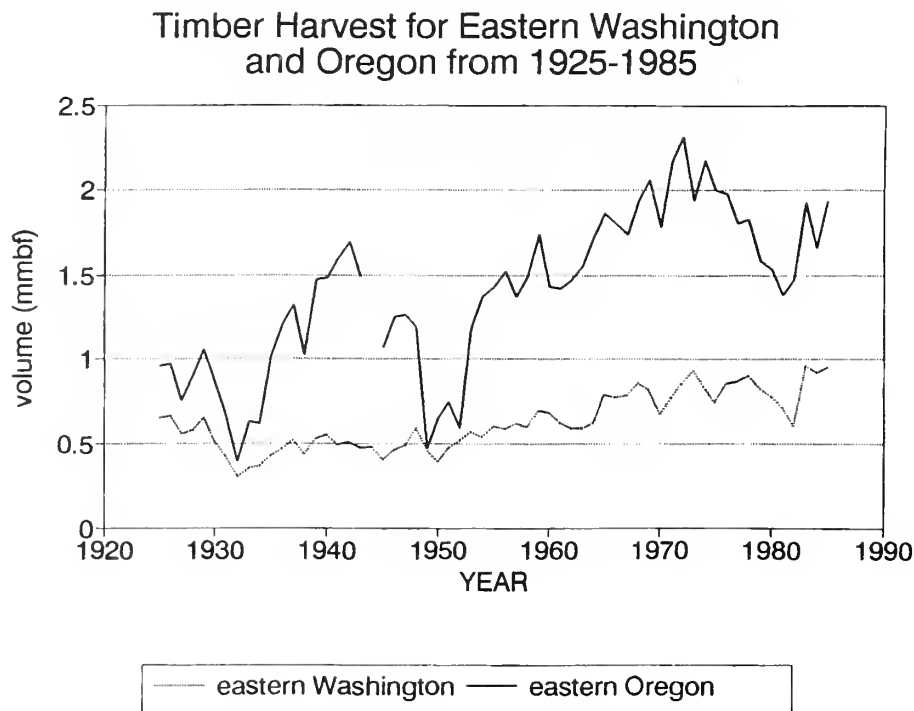


Figure 3. Timber harvest rates in eastern Washington and Oregon, 1925-85 (Washington Department of Natural Resources 1985; Oregon Department of Forestry 1985).

A common management approach used by the National Forest system in countering adverse effects on water quality requires applying site-specific best management practices, (MacDonald and others 1991). Cumulative effects of individual, dispersed, timber-harvest and road-related activities, however, commonly increase system-wide damage, recovery times, and susceptibility to large runoff events and related disturbances (Peterson and others 1992). Depending on the physiographic characteristics of a watershed, such events can adversely affect not only water quality but also riparian and aquatic habitats. Common hillslope, floodplain, riparian, and stream responses include mass wasting, streambank erosion, and changes in channel geomorphology. When adverse effects occur, they are usually in violation of Section 319 of the Clean Water Act.

The management methods used to counter adverse effects illustrate many of the issues pertaining to influences of timber harvest on forest hydrology. Important issues include de-synchronization or alteration of stream flow regimes caused by logging and the reduction of tree cover; soil compaction thresholds and streamflow; and wetted soil mantle and runoff practices after clearcutting (Harr 1987). These issues, related problems, and the management approaches to address adverse effects of timber harvest and road building are discussed in the select stream and watershed management approaches section and the recommendations section.

Fire management—Forests of differing stand structures and landscape patterns in eastern Washington and Oregon have developed under natural fire regimes of both high-intensity crown fires and low-intensity underburns. Because of the dry climate and natural fire history, most forest stands tended to be less than 400 years old. Frequent but low-intensity fires maintained open stands and favored fire-tolerant species. During the past century, however, fire suppression has altered the natural fire regime and therefore the stand compositions of eastside forests. These forests now contain fewer fire-tolerant tree species and dense understory vegetation (Mullan and others 1992). High fuel accumulations have caused more intense and destructive fires than in the past. Frequently, over the past few decades, extensive fires in eastern Washington have been hot fires with substantial effects on forest nutrient status and soil conditions (Grier 1975, Tiedmann and others 1979).

The increased severity of these fires can alter the amounts and qualities of nutrients, sediments, and organic debris delivered to stream channels. For example, studies of nutrient transfer to streams in eastside forests of Washington and Oregon indicate that amounts of organic nitrogen roughly doubled during the first year (Tiedmann and others 1979). The most significant effects of fires on streams and rivers are the increases in water, sediment, and debris delivered to the channels. Studies in eastern Washington have shown that streamflows increased after fires (Klock and Helvey 1976). The cumulative effects of rapid snowmelt, high-intensity rainstorms, and the destruction of aboveground and belowground vegetation in denuded watersheds of the Entiat River basin, for example, resulted in massive debris torrents with frequencies 10 to 28 times greater than before fires (Helvey 1980). Such large inputs of sediments and debris can overload the channel transport capacities, thereby altering stream habitat complexity. Although the redistribution of fine sediments and spawning gravels can destroy fish eggs and displace juvenile fish and aquatic insects, both the relocation of gravels and large woody debris can create new spawning and rearing habitats.

Livestock grazing—Much of the land area of eastern Washington and Oregon is favorable for livestock grazing. For example, about 50 percent of the Columbia River basin is suitable range and most of this is managed by the Forest Service and the Bureau of Land Management. A recent Federal report on the condition of these range lands indicates considerable over-use and damage during the past century. About 50 percent of the Forest Service and Bureau of Land Management range lands in the western United States were reported in fair to poor condition based on vegetative potential (General Accounting Office 1988; figs. 4A, B). In 1985, a similar report for non-Federal range lands in Oregon indicates that about 78 percent of private lands were also in poor to fair condition based on vegetative capacity (Soil Conservation Service 1985; fig. 5).

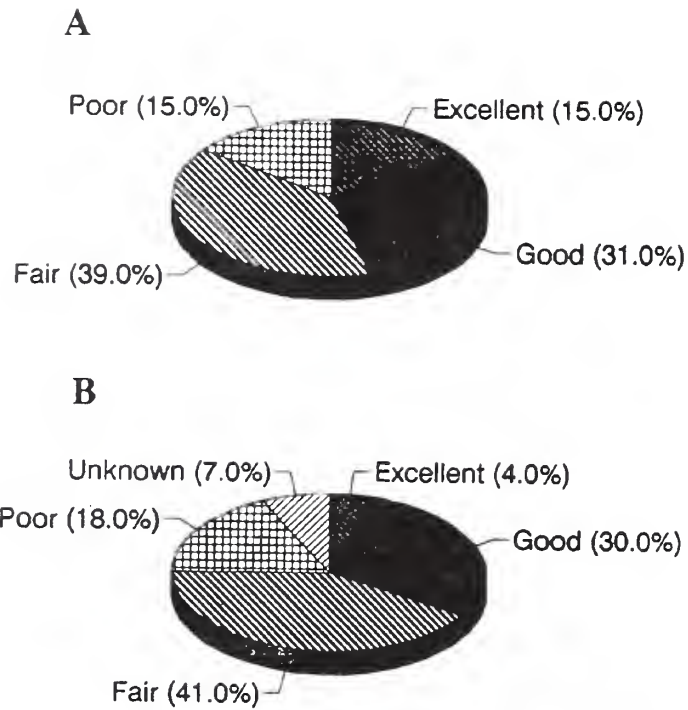


Figure 4. Range conditions on lands in the western United States in 1987: A) Forest Service lands; and B) Bureau of Land Management (BLM) lands (Government Accounting Office 1988).

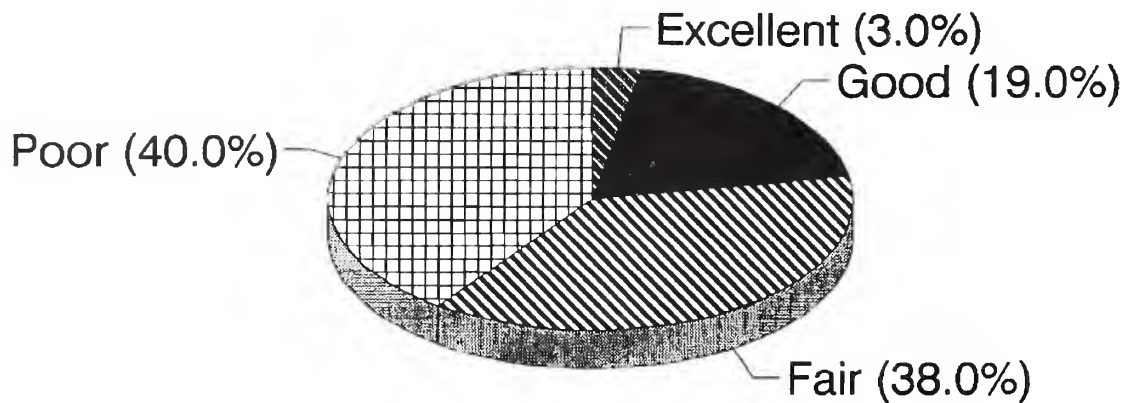


Figure 5. Range conditions on non-federal rangelands in Oregon (Soil Conservation Service 1985).

Livestock grazing began with the arrival of miners and settlers during the second half of the 19th century. Overstocking and overgrazing of the available ranges during the late 1800s and early 1900s caused widespread damage, altering plant diversity and compacting soils (Elmore 1992). Over time this grazing has caused ranges to become highly vulnerable to increased soil erosion, with degraded riparian and wetland vegetation, degraded streambanks, and lowered water qualities and flows. Changes in stream and riparian habitat structure commonly followed heavy grazing because of increases in surface runoff and sedimentation, and decreases in groundwater infiltration (Hibbert 1976, Platts 1981). Erosion and sedimentation in streams reduced or destroyed fish habitats and riparian habitats changed from trees/willows/sedges to brush and bare soil (Kovalchik 1987; Kovalchik and Elmore, in press).

The growth of the livestock industry in eastern Washington and Oregon increased the number of animals beyond the carrying capacity of the available range (Platts 1991). By the 1920s overgrazing of Forest Service lands and drought conditions caused further deterioration. By 1934, range conditions became so serious that Congress passed the Taylor Grazing Act to improve public rangelands. Through the 1960s and 1970s the Forest Service, Bureau of Land Management, the U.S. Soil Conservation Service, and private landowners improved grazing practices through a variety of management strategies. But even more attention was needed to accurately assess the influences of grazing on riparian and stream ecosystems at the river basin or landscape scale. For example, improved range conditions have mainly occurred in upland ranges, with minimal gain in riparian and stream conditions (Behnke and Raleigh 1978). Concern has developed about whether present grazing strategies are applicable to solving grazing effects on riparian and stream habitats. The livestock industry's recent shift from grazing sheep to cattle is an example: cattle prefer streamside areas, and increased grazing pressures have stimulated concerns about the deterioration of riparian and stream habitats (Platts 1981, 1991). Although, at specific sites various grazing strategies can be used to restore riparian habitat, how riparian and stream ecosystem function together across larger landscapes like river basins is poorly understood (Elmore 1988, Elmore and Beschta 1987, Wissmar and Swanson 1990). The case studies for select river basins below provide information about regional grazing histories.

Mining—Mining in eastern Washington and Oregon has been based on minerals such as gold, silver, copper, nickel, and chromium, as well as gravel and building stone. Because many of the deposits were low grade and widely scattered, however, mining has declined during the past half century. Nevertheless, mining continuously influences stream and riparian ecosystems because of habitat modifications of past placer and hydraulic methods (1860s-1900), erosion and leachates from deposits of lode mining (after 1900), and bucketline dredges (1900 to 1930). Because water was scarce for working placer and hydraulic operations, from the 1860s to 1900, long ditches were commonly used to divert large amounts of water to the mining areas. In the Blue Mountains of Oregon, for example, the El Dorado ditch led more than 100 miles from the headwaters of the Burnt River to the placers at Malheur, near Willow Creek (Dicken and Dicken 1979). Pits and scars from these mining operations can still be seen in some localities. An excellent history of the influences of mining and the extraction of minerals on streams is in Nelson and others (1991).

More recent effects of mining on stream and riparian ecosystems include leachates from leach mining, such as cyanide chemical-leach mining for gold—based on mineral extraction processes in old mine deposits; and the excavation of stream channels and floodplains for sand and gravel. Currently, leach mining near Chesaw in the Okanogan Highlands are under consideration by the Battle Mountain Gold Company and the Washington State Natural Resources Committee.

Okanogan County is an excellent example of the value of nonmetallic mining products. Historically, the value of sand, gravel, gypsum, and limestone products has been several times that of precious metals (Wilson 1990). The same trend is apparent in most of the counties in eastern Washington and Oregon (Highsmith and Kimerling 1979). The mining of river bed gravel deposits and the construction of levees can both be detrimental to salmonid habitats (Pauley and others 1989, Rivier and Sequier 1985). Historically, gravel was removed by dredging within the wetted perimeter of a river as well as from gravel bars.

Since 1983 in the State of Washington, gravel has been mined by taking alluvial material only above the summertime low-water wetted perimeter, and by using such equipment as bulldozers and front-end loaders (Pauley and others 1989).

Gravel mining in rivers can create biological imbalances by altering flow patterns in channels and overloading aquatic habitats with sediments (Carling 1987, Rivier and Sequier 1985). The resultant changes are evident in key physical factors such as substrate composition, depth, velocity flow patterns, turbidity, suspended sediments, and temperature that determine the abundance and biodiversity of aquatic organisms (Binns and Eisermann 1972, Bjorn and Reiser 1991). For example, excessively turbid waters can reduce light penetration and increase deposition and silting by fine sediments. These physical changes can limit photosynthesis and alter feeding, migration behaviors, population structures, and usable habitat of different macroinvertebrate and fish assemblages (Etnier 1972, Milner and others 1981). The duration of effects and the resultant erosion and deposition of streambed materials can be related to the length and width of channel habitat disturbed, stability of substrates, and type of alteration (Moore and Gregory 1988, Wydoski and Helm 1980).

Irrigation—Water withdrawal uses in eastern Washington and Oregon include rural domestic, stock watering, irrigation, public water supply (municipal and light industrial), and industrial. Of the three most important off-channel uses—irrigation, industries and municipalities—the dominant off-channel use is irrigation. Irrigation accounts for about 10 times the combined volume of water withdrawn by municipal and industrial systems (Highsmith and Kimerling 1979). The major regional problems related to water withdrawal for irrigation include water storage and drainage, high water temperatures, pollutants, and low streamflows in smaller drainages. Dewatering of streams affects salmonid habitats, riparian ecosystems, and associated wetlands.

High water temperatures and gas supersaturation, serious problems in the lower Snake River, can also pose problems in the polluted Yakima River. Although improved water treatment facilities have been responsible for decreased biochemical oxygen demand (BOD), an apparent widespread problem in stream waters is caused by organic and inorganic toxic materials and sediments from nonpoint sources of pollution. More than 20 million acre feet of irrigation return flows dominate cumulative nonpoint sources in eastern Washington and Oregon (Highsmith and Kimerling 1979). Other major problems include drainage from over-irrigation and seepage, increases in soil salinity, flood plain damage, and alteration of groundwater storage.

Irrigation and related water uses have expanded during the past 25 years in eastern Washington and Oregon. Increased withdrawal of water is related to new types of sprinklers and other irrigation based developments. Out-of-state promotions of developments emphasizing farming, recreation and retirement have been stimulated by irrigation from wells and by large tracts of cheap land. This has greatly increased water demands and the possibilities of insufficient recharge of wells. When combined with increased cut-over lands in marginal forests and expanded conversions to cropland, these problems suggest increases in resource conflicts in the near future (Dicken and Dicken 1979, National Research Council 1992a).

HISTORY OF LAND AND WATER USES IN SELECT RIVER BASINS

The case histories focus on the chronology of natural resource uses and the health of streams and riparian ecosystems. The select river basins include the Okanogan and Methow River (north-central Washington), the Little Naches River of the Yakima River drainage (central Washington), the Grande Ronde River (eastern Oregon), and the John Day River basin (north-central Oregon). The chronology for the Okanogan and Methow River basins focuses on the events and developments of the last century and early 1900s that shaped the present day landscapes and on socioeconomic conditions in eastern Washington and Oregon. Summaries for the Little Naches, Grande Ronde, and John Day River basins review specific land and water uses that have influenced stream and riparian ecosystems in eastern Washington and Oregon.

Okanogan and Methow Rivers (North-Central Washington)

The history of settlement, natural resource use, and conflicts in the Okanogan country represents a mesocosm or time capsule of the events that shaped present landscapes and socioeconomic conditions. The Okanogan valley, as well as most of north-central Washington, was isolated but not insulated from the principle east-west corridors of commerce in the Pacific Northwest. The valley's location and the late arrival of the railroad slowed development and preserved frontier-like conditions into the 20th century. Fur trading, overland exploration, mining, encounters between Euro-Americans and Indians, creation and modification of Indian reservations, cattle drives, homesteading, conflicts between sheepmen and cattlemen, overgrazing of ranges, railroad building, irrigation development, logging and dam building—all were significant aspects of frontier life and development in north-central Washington. Many of these activities had substantial effects, as can be seen from the following summary and in table 5.

Table 5—Chronology of major settlement, natural resource uses and related developmental events in north central Washington. Asterisks (*) indicates historical activities with potential effects on the health of riparian areas, stream habitats and watersheds of riverine valleys. Major sources include Steele 1904, Kerr 1931 and Wilson 1990.

Date	Event	Activity
1811	Fur trade begins	John Jacob Astor (Pacific Fur Co.) establishes trading post at the confluence of the Okanogan and Columbia Rivers.
1816	Fur trading	* Supply of beaver nearly exhausted in the Okanogan country suggesting beaver removal changed riparian and stream conditions.
1846	U.S.- British boundary	International boundary set at 49th parallel.
1847	Fur trade ends	Hudson Bay Co. ends fur trade.
1853	Washington Territory created	Isaac Stevens first governor of Washington Territory.
1855	Yakima Reservation created	Yakima Indian Reservation formed (1.2 million acres).
1858	Gold discovered in British Columbia	* Gold rush on the Cariboo Trail in the Okanogan country.

Table 5—cont.

Date	Event	Activity
1859	Gold discovered in Okanogan	* Gold discovered in lower Similkameen. Placer mining of river channel and banks may have degraded the river ecosystem.
1860-1880	Water diversion in lower Methow River	* China Ditch constructed above mouth of Methow River to deliver large volumes of water to sluice boxes for placer mining suggest potential damage to riparian and stream habitats. Facility converted to irrigation in the 1920's by the China Ditch reclamation district, destroyed by 1948 flood.
1860's	Cattle drives on the Cariboo Trail	* Overgrazing of ranges suggests potential for erosion in the floodplains of the Okanogan River. Cattle drives on the Cariboo Trail supplied mining towns in B.C.
	Settlement in Okanogan	Hiram F. Smith near Lake Osoyoss first resident cattle rancher.
	Salmon harvest	* Weir across the Okanogan River by settlers and catching salmon leads to possible over harvest of returning adult fish, about 20 wagon loads of salmon per day.
1870	Population, 34 non-Indians	Federal census of the Okanogan valley.
1872	Colville Reservation created	Colville Indian Reservation formed to resolve land ownership questions caused by patterns of white settlements. Area east of Okanogan River included today's Ferry County (2.5 million acres).
1878	Population, 44 non-Indians in Okanogan	Stevens County census. Area of Stevens County from 1864 until 1888 included district today's counties of Okanogan, Chelan, Ferry, Stevens and Pond Oreille.
1879-80	Moses reservation created	Area west of Okanogan to crest of Cascade Mts and from Lake Chelan north to the 49th parallel.
1880's	Settlements increase in Okanogan valley	* Population of settlers begins to increase suggesting land clearing and conversion of riparian areas.
1886	Okanogan mining boom	* Mining boom began west of Okanogan River and miners, ranchers and settlers move onto the Moses Reservation. Placer mining of river channel and banks, lode mining and numerous poorly designed concentrating and flotation mills, high daily water demands (e.g., 60,000 gallons) , and production of sediment wastes may have degraded several river ecosystems.
	Moses Reservation	Moses reservation opened to miners and settlers.
1883-1916	Railroads	See Text
1888	Okanogan County created	Included today's Okanogan & Chelan Counties.
1889	Washington becomes a State	

Table 5—cont.

Date	Event	Activity
1890	Population of 1,509 non-Indians in Okanogan	Okanogan County census. Okanogan County included today's counties of Okanogan and Chelan.
1893	Okanogan mining declines	Price of silver declines during U.S. recession.
1894	Flood	* 100 year flood and debris-dam break flood destroy towns of Conconully and Silver. High probability of major changes in stream and riparian habitats.
1890s	Mining in the Methow	Slate Creek district (Mammoth Mine) near Hart's pass supplied by new town of Winthrop (1891). The Red Shirt & Alder Mines of the Twisp district were major producers.
1895	Mining resumes in Loomis District	* Numerous rich mines resume operations. Ten years of intense lode mining (1895-1905) and numerous poorly designed concentrating and flotation mills, high daily water demands, and production of sediment wastes may have degraded river ecosystems.
1899	Okanogan County reduced in size	Formation of today's Okanogan & Chelan Counties. Populations were 2,839 in Okanogan and 1,321 in Chelan counties (Steele 1904).
~1900	Sheep arrive the Okanogan	* Sheepmen begin to settle in the Okanogan.
	Sheep drives	* Overgrazing of summer ranges suggest increased erosion of watersheds and modification of riparian & stream habitats.
1905	Irrigation development	* Removal of water from rivers and streams reduced or negated the development of riparian & stream habitats.
~1910	USFS created	
~1916	Railroad building	* Alteration of river valleys led to erosion, removal and constraint of geomorphic features of riparian & stream habitats.
1916	Homestead Act	* Opened homesteading and decreased open range.
+ 1920s	Logging	* Alteration of watersheds led to erosion, changes in hydrologic and geomorphic features of riparian & stream habitats.
+ 1930s	Dam building	* Created migration barriers and altered riverine habitats for fish (e.g., changed temperature and predator conditions).

The British first established a presence in the region in 1811, with the beginning of the fur trade. In 1816, the British-owned North West Company built Fort Okanogan on the same site as J.J. Astor's trading post. Furs coming out of British Columbia (New Caledonia) and Fort Colville were collected and shipped downstream, and supplies were received from Fort Vancouver down river at the mouth of the Columbia. In 1821, the Hudson Bay Company took over the North West Company. During 1834-36, the original Fort Okanogan was replaced with a new Fort Okanogan closer to the Columbia River.

In 1846, the international boundary was set at the 49th parallel, ending joint occupation by British and Americans. The large influx of immigrants to Oregon during the 1840s assured American control of the Northwest. The following year, the Hudson Bay Company ended fur trade between British Columbia and Fort Okanogan. The British and Americans expended considerable effort in surveying the 49th parallel between 1858 and 1861.

The next decade was relatively quiet but, in 1858, a gold rush in the upper Frazer River country drew large parties of miners to the Cariboo Trail along the Columbia and Okanogan Rivers. The previous discovery of gold in the vicinity of Colville and the Yakima River of Washington in 1855 had already enticed miners to the north country (Steele 1904). A large party of miners (about 160) traveling to Frazer River gold strikes had initial, violent encounters with Indians of the region. Three were killed and 20 wounded by Indian ambush in McLoughlin Canyon, about 20 miles south of the Canadian border on the Cariboo Trail.

In 1859, gold was discovered in the lower Similkameen River valley near the Enloe Dam, west of Oroville, Washington (table 5). Mining claims were not regulated until the 1872 Mining Act. From 1859, the booming population of 1200 to 3000 placer miners worked the Similkameen River channel, until they stam-peded north to large gold strikes in the Cariboo country of British Columbia during 1860.

In the early 1860s, another direct effect on riverine ecosystems appeared: the overharvesting of returning adult salmon in the Okanogan River by settlers. John Utz, who had settled near Lake Osoyoos, constructed a weir across the river. He trapped as many as 20 wagon loads of salmon a day to sell to Indians. These early actions combined with the later effects of intensive commercial fishing, the building of the Columbia River dams, and other habitat losses in the Okanogan basin, devastated anadromous fish runs. Spring chinook salmon became extinct, native summer/fall chinook salmon and summer steelhead stocks were virtually eliminated, and sockeye salmon runs were depressed (Jim Spotts, pers. comm.).

From the 1860s to 1900, mining took place throughout the Okanogan country, from the Chelan Mountains eastward across the Methow to the Conconully Range. Some of the most extensive silver and gold strikes (placer and lode mining) were on Silver Creek, northeast of today's Okanogan City in the Salmon and Ruby Districts—the towns of Ruby, Conconully—Loop Creek, and along the Similkameen River near Loomis. During the 1886-93 boom years, the Ruby-Conconully Districts were considered among the richest mining areas in the Pacific Northwest (Wilson 1990). Other important districts were the Palmer Mountain, Chesaw, Methow, and Twisp. The first discovery in the Methow valley was in 1887 at the town of Silver near Twisp. During the boom period and the 1890s, the abundance of natural resources and the area's mild climate also induced settlement by farmers, stockmen, and lumbermen.

Maps of mining districts (Hodges 1897) suggest that the locations of numerous mining claims were in stream channels and adjacent streamside areas of rivers and their tributaries. Placer mining of river channel and banks, lode mining, and wastes from numerous poorly designed concentrating and flotation mills may have degraded several river ecosystems (35 to 40 mills in Okanogan County). The Salmon Creek watershed is a prime example of an affected ecosystem, a watershed altered by the rapid construction of the Ruby and Conconully townsites and by development of claims throughout the subbasin. By 1888, Ruby City extended a quarter of mile on Salmon Creek about 13 miles northeast of Okanogan City. The destruction would have been particularly devastating to spring chinook salmon, a salmon run now extinct in the Okanogan basin.

Mines of the region were supplied by stern-wheeled riverboats on the Columbia River from Wenatchee to Brewster and by the North Pacific railroad. Railroads came to Spokane Falls and Ellensburg in 1883, Colville in 1890, Wenatchee in 1892, and the Okanogan valley in 1916 (Steele 1904, Kerr 1931). The effect of railroads on population growth was evident in Chelan County, where the population increased from 1321 in 1899 (table 5) to 3931 in 1900, and 7547 in 1903. Twenty percent of the population was in Wenatchee during 1903 (Steele 1904).

Cattle began to appear in considerable numbers during the 1860s in north-central Washington. The cattle were driven along the Cariboo Trail, the same trail that led to the gold strikes in the Frazer River and Cariboo mining districts north of the Canadian border. Six hundred miles from The Dalles to the upper Frazer River valley, the Cariboo Trail supplied beef, which often originated in the Willamette and Yakima valleys, to the northern mining camps. During the peak years of 1862-64, British customs at Osoyoos Lake collected duty on 7720 cattle, 5378 horses, 1317 sheep, and 948 mules. Ben Snipes, a principle cattlemen using the Cariboo Trail, reportedly grazed over 100,000 head of cattle and 20,000 horses in the Yakima valley (Wilson 1990).

The Yakima valley was also the principal supplier of cattle to Seattle. Originally supplied with beef driven from the Yakima valley across Snoqualmie Pass, the range of the Yakima valley became over crowded with cattle in the 1870s, and the cattle company Phelps and Wadleigh shifted some of their operations to the Okanogan. Until the winter of 1880-81 forced them into receivership, they were the largest cattle buyers in the Washington territory. Such winter weather demonstrated the problems of grazing livestock in the Okanogan valley throughout the year. Nevertheless, the cattle industry of the valley managed to survive. In 1896, cattle were being driven from the Okanogan valley to Wenatchee for shipment via the Great Northern Railroad to Seattle.

The Cariboo Trail opened the Okanogan country to the outside world and led to the first white settlers in the area in the early 1860s. Hiram F. Smith, the first resident cattle rancher of the Okanogan settled near Lake Osoyoss in about 1860. He planted an apple orchard, ran a trading post, and made the first discovery of gold-bearing rock. Opening of Colville Reservation in 1896 and 1898 led to mining claims and premature staking of lands for farmland and stock ranges. Mineral production during the mining boom of Okanogan County in Washington State ranked behind Ferry, Stevens, and Chelan counties.

As settlers began to move into the Okanogan County, the number of horses and other livestock climbed steadily between 1890 and 1905. Although these increases were considerable, other counties with earlier settlement and growing populations as well as higher agricultural production of wheat, for example, showed even greater increases in livestock. In 1904, Whitman County had 26,706 horses and 44,074 cattle compared to Okanogan's 7000 horses and mules and 21,058 cattle (table 6).

Table 6—Changes in numbers of livestock in Okanogan County between 1890 and 1904.*

	1890	1900	1901	1902	1903	1904
Horses and mules	2,328	4,930	5,731	6,460	6,942	7,000
Cattle	4,744	9,157	10,997	12,805	16,411	21,058
Sheep	—	2,098	6,078	25,888	28,770	31,757
Wagons and carriages	206	657	869	1,025	1,126	1,283

* Modified after Wilson (1990). Data source include State of Washington, Its Resources, Natural, Industrial and Commercial, c. 1905, The Washington State Bureau of Statistics.

Sheepmen began to locate in Okanogan County in about 1900. Sheep grazing attracted the attention of established cattle ranchers, who believed that sheep ruined pasture for livestock. One incident near the town of Okanogan (during the winter of 1902-03) resulted in a night raiding party and the slaughter of an estimated 900 sheep in a corral.

In Okanogan County during the turn of the century, sheep numbers increased dramatically, from less than 2000 before 1890 to about 31,757 in 1904 (table 5). Many other pre-settled counties had even more sheep, however; Yakima, the greatest sheep producing county, had about 147,000 sheep in 1904.

During the mid-1890s, agriculture replaced mining as the principal economic activity and, in Okanogan County between 1900 and 1903, crops increased from about 1500 acres to 13,000 acres. Farmable lands with minimal irrigation were in river floodplains. The extent of the Okanogan River floodplains and presence of wetlands (mainly from Tonasket to Osoyoss Lake) is suggested by reports in 1882 of dense swarms of mosquitoes (Pierce 1882). By 1900, water was clearly the limiting factor and irrigation projects would be needed to sustain population growth and agricultural development.

The Okanogan Reclamation Project was authorized by Congress in 1905, and was one of the first irrigation projects undertaken by the U.S. Reclamation Service. The project was approved without sufficient investigation into water supply in terms of the local climate and hydrologic regime of the watersheds. The Reclamation Service encountered problems not only because of the failure of the watershed to furnish sufficient runoff, but because of poor management practices. These problems included inexperienced contractors, water being put on lands with sandy soils not suited for irrigation, and public funds being misused by providing water for private lands. By 1931 when a majority of the irrigated land was under the Okanogan Irrigation District, electric pumps and not irrigation ditches provided most of the water from the Okanogan River (Kerr 1931).

Irrigation systems caused problems for migrating salmon. The main irrigation canals on the floodplains of Okanogan River, for example, ran parallel with the river channel, intercepting tributary streams, and effectively blocking access to tributary stream by anadromous fish migrating from the main river. Such systems of irrigation canals were less extensive in the Methow and Similkameen River valleys.

Little Naches River: Yakima River Basin (Central Washington)

This case history of land and water uses covers two topics: settlement and resource uses in the Yakima River basin; and land-use and changes in stream and riparian habitats in the Little Naches River. The Little Naches River is a tributary to the Naches River in the headwaters of the Yakima River system. The basin is 45 miles northwest of Yakima, Washington, slightly north and east of Mount Rainier.

Settlement and resource uses in the Yakima River basin—Before 1850, the Yakima River basin was primarily unsettled by pioneers; most of the population was Native American. Although, the Native society was primarily one of hunting and gathering, canal systems for irrigated crop cultivation had been built under Catholic missionary authority (Davidson 1953). Catholic missions at Parker Bottom, Tampico, and Naneum were the first non-native settlements in the valley. Once the missionaries were established, settlers followed rapidly. The McClellan exploration party surveyed the Naches Pass area for a route to Puget Sound during the 1840s and stimulated the flow of immigrants (Gossett 1979). The first permanent settlers arrived around 1860 near Moxee, bringing several hundred head of cattle. Not long after, the Yakima Valley became one of the primary areas for cattle ranching east of the Cascades. Sheep grazing soon became one of the primary uses of the upper tributary watersheds, however, sheep were driven along “driveways” into the forests for the summer foraging from June through October, then driven back to the valley for the winter. Cattle were also driven into the upper tributaries, grazing on the alluvial flats and glacial valleys. The cattle drives peaked during the 1880s Sheep ranching peaked at the turn of the century, and again during World War I, when prices and demand for sheep products were at their greatest. Before full establishment of permitting and allotment systems in 1905, records on numbers

of cattle and sheep are incomplete. Records for 1907 indicate 260,000 sheep were permitted in the Naches and Tieton basins (Uebelacker 1980). During this period, the Naches basin held 55 percent of the sheep grazed in the Yakima Valley and 83 percent of the cattle and horses (Carter 1990).

By 1907, the public recognized that areas of the Forest were being overgrazed. Livestock grazing, the use of driveways, and burning of the forest to promote pasture all were in direct conflict with other uses of the forest, such as watershed-irrigation projects, recreation, and timber. Sheep and cattle driveways had been established along most of the ridge crests between tributary drainages. Many of these areas naturally are sparsely vegetated with erosive soils. The driving of thousands of sheep and cattle over them during the dry season likely exacerbated the situation during the wet seasons. Most upland tributaries of the Yakima drainage basin exhibit increased surface runoff and erosion during the rainy season. Surface erosion and debris slides are common and can be long-term sources of sediment. Furthermore, wildfires and localized burning to increase grazing areas likely added to surface erosion and sediment-supply problems. By 1909, the Manastash, Cle Elum Ridge, and the main Taneum valley were all closed because of overgrazing. Situations like this sparked large-scale conflict between the sheep growers and the ever-increasing agriculture and orchard industry. By 1930, the numbers of sheep permitted on remaining allotments was probably less than 10 percent of peak numbers. During this period, sheep were being trucked to their range because driveways were banned. Valley bottoms and meadows were closed to grazing.

In general, the early effects of the sheep and cattle industry were heavily concentrated in the headwaters and tributaries—such as the Little Naches of the Yakima River system. In contrast, the burgeoning irrigation systems and agricultural industry were concentrated in the Yakima Valley proper and other tributary valleys. The development of irrigation systems changed the face of the area and parallels the development of the valley. In 1860, the Toppenish-Simcoe canal system was started near the Yakima Indian Reservation and, by 1869, the large drainage canal from the Naches had been built to irrigate lands below the confluence of the Naches with the Yakima River. The construction of the Sunnyside Canal in 1893 kicked off the agricultural and development boom. Irrigation and the extension of the Northern Pacific Railroad into the Yakima valley opened thousands of acres of previously unarable land to development. Originally, hay and feed crops were grown to supply the cattle and sheep industry, but eventually these gave way to row crops, permanent crops such as hops and grapes, and orchards.

In 1905, the Federal Bureau of Reclamation took over control of irrigation systems. The Reclamation Enabling Act gave them full power to appropriate waters for irrigation, including eminent domain for rights of way for canals and reservoirs. No minimum fish flows or other fish protection measures were designated in the Act. Fish ladders and screens were not required until the Fish Ladder Law was enacted in 1915. Between 1905 and 1915, migrating and resident fish populations were devastated. Many of the early systems, such as the Sunnyside Canal and the Tieton Canals, had been constructed without fish ladders or screens. Although some fish ladders were built after 1915, screens, which keep juvenile salmon from being trapped in the canals, were not placed until the 1930s. An estimated 90 percent of the annual runs of salmon and steelhead trout had been destroyed by the early 1990s. The primary factors leading to the decline are (Fast and others 1991) construction of dams and canals without adequate fish passage facilities, such as ladders and screens; log drives tearing up spawning and rearing habitat; and indiscriminate local and commercial fishing.

In the areas below the city of Yakima, other major effects on fish production were the increase in water temperature, high suspended-sediment loads, and chemical pollutants from agricultural runoff. In tributary areas, construction of reservoirs and 100 percent appropriation of water for irrigation contributed to dangerously low flows during summer.

Although agriculture is still one of the major industries in the Yakima area and the associated effects from irrigation still remain, the large-scale impacts of livestock grazing practices on the forest areas has probably diminished since the early decades of the twentieth century. Sediment input from chronically eroding

areas may still be a problem in many places, but the relative impact has probably lessened. But the advent of accelerated timber harvesting, road construction and improvement of harvesting methods followed closely on the heels of grazing. Full recovery of forest streams is highly unlikely to have been achieved before the effects of timber harvest were felt.

Land-uses and changes in stream and riparian habitats in the Little Naches River—The Little Naches River is a fifth-order basin with a drainage area of 398 km². The mainstem and Middle Fork of the River is the boundary between Kittitas County to the north and Yakima County to the south. It drains east and south from the Norse Peak Wilderness, Pyramid Peak, Blowout Mountain, and Quartz Mountain in the southern Cascades. Almost the entire river basin lies within the Wenatchee National Forest, with portions of the upper basin under checkerboard ownership with Plum Creek Timber Co. The mainstem of the river is about 21.2 km long up to the confluence with the Middle and North Forks. The valley roughly alternates between constrained and unconstrained reaches, with the lower end generally more constrained between basalt slopes, and the upper end spreading out into broadly unconstrained alluvial valleys.

Peak flows occur in May and June, with another smaller peak in December and January. Low flows occur August through October, lowest in late August to September. Average annual stream flow for 1966 to 1987 was 204 cfs and the average peak flow was 758 cfs (unpublished data, Bureau of Reclamation, Ellensburg, WA). The upper end of the basin near Pyramid Peak receives more than 100 inches of rain per year, the middle basin from the North Fork to the South Fork receives 60 to 80 inches, and the lower basin 45 to 60 inches of rain.

The Naches River drainage is the largest tributary in the Yakima system. The upper reaches of the Naches provide summer and fall rearing habitat for 30 to 37 percent of the anadromous salmonid fry and smolts in the Yakima Basin (Fast and others 1991). In addition, 59 percent of the remaining harvestable timber in the Yakima basin is in the Naches drainage (Wenatchee National Forest 1990). The Little Naches River is one of the primary harvest areas with a large percentage of uncut timber. The Forest Plan (Wenatchee National Forest 1990) indicates that more than 50 percent of the basin will be cut under intensive and selective methods over the next decade. Since the 1960s, 35 percent of the harvestable acres in the basin have been cut. If the goals of the Forest Plan are met, the percentage harvested will be near 90 percent by the year 2000.

Many species of fish are native to the Little Naches basin—sculpin¹, dace, suckers, whitefish, sunfish, and of course, salmonids. Besides original runs of spring and fall chinook, winter and summer steelhead, and cutthroat, before the 1950s a small run of coho had been reported. Today, only a few spring chinook return to the Little Naches and an even smaller number of steelhead. Spring chinook redds have increased in the Little Naches since 1981, however, and between five and 11 redds have been sighted above Salmon Falls since the construction of the fishway in 1987 (Woods and Russell 1991).

Since 1985, steelhead have been planted in Crow Creek and other tributaries in the Little Naches River from hatchery stock, but smolt survival has been poor. Resident populations of rainbow, and brook trout, are still present. Each year, about 45,000 individuals of these species were stocked in the upper tributaries of the Naches River to boost the sport fishery opportunities. Besides these commercially or recreationally important species, several other fish species reside in the Little Naches basin: sculpin, dace, lamprey, and suckers.

¹ Scientific names for all taxa are given in Appendix A.

Land-use history—Land uses in the Little Naches River basin consisted of intensive grazing (from 1880 to 1930), small-scale selective harvest in the valley bottoms, and considerable recreational use. Before 1900, no developed roads were in the Little Naches Basin, except the Naches Pass trail, built into a road in that year (the "1900" road). The Naches Pass trail was finally completed as a wagon train route to the Greenwater River basin in 1853. Since its inception, the trail was continually being used, improved, and surveyed for development. At one point, it was slated to become the next cross-Cascade pass.

Before 1910, the Chinook Pass road (Highway 410) had been completed 6 miles up the American River, including the bridge across the Little Naches. The real turning points for the basin itself, however, were improvements in the F.S. Rd. 1900 road by graveling in 1929 and paving in 1934 (6 miles from the mouth up to Jungle Creek). The original Raven's Roost road was up Crow Creek, built in 1934 for the purpose of constructing and operating a lookout tower. No new roads were built between 1934 and 1962, but increased timber harvesting after 1962, caused additional road building to access harvest areas. The FS Rd. 1900 road was eventually improved and extended all the way to Pyramid Peak, which spurred increased road density and use of the entire watershed. From the turn of the century to 1962, only 20 to 30 miles of roads were in the basin, but between 1962 and 1990, an additional 300 miles were constructed. Road densities in 1990 ranged from 1.6 to 5 mi/mi² (Ehinger, pers. comm.).

Before timber harvesting, the single greatest effect on the basin was the widespread grazing that lasted for 60 to 70 years. Before the allotment and permitting systems were established, areas used for grazing and the number of animals grazed was uncontrolled. The ridge crests were heavily used as grazing, sorting, and driveway areas.

Small-scale burning of meadows and low brush areas by the local Native Americans and sheepherders was common from the 1850s through the 1920s. Much of the crestal uplands along the south and north ridges were repeatedly burnt. Surface erosion and debris slides from these areas could have contributed significantly to open riparian canopies in the headwater streams. Also, wildfires can damage vegetation and soils and initiate intermittent to continuous long-term erosion and delivery of sediment and organic debris to streams (Swanston 1991). In the Little Naches River, chronically eroded areas were identified in aerial photos as long as 50 years after the burning and grazing had been diminished (Smith 1993).

The allotment system was begun in the 1880s in response to complaints about the grazing and burning of the forest. The system was not fully in place until 1905, but the numbers of sheep and cattle were drastically reduced. In 1923, six allotments were present along the entire westside and up the Matthew Creek drainage, which altogether permitted 7300 ewes plus lambs from June through October (Carter 1990). The valley bottom was used for horses as well as sheep. Reports to Congress in the 1930s indicate that the grazing areas in the Forest were heavily degraded (Anonymous 1930, Cooperative Western Range Association 1938). Driving of sheep to summer range was discontinued in the 1930s and sheep had to be trucked to the range. By 1950, many of the allotments were abandoned or severely reduced in number.

One of the unique aspects of the Little Naches land-use history is the relatively late timber harvest relative to harvest on the westside of the Cascades. The basin was fairly isolated and access from the Yakima Valley was difficult, partly because of steep landforms in the Horseshoe Bend area of the Naches River (Gosset 1979). Before the late 1950s harvest was limited to extracting large trees from the lower valley bottoms and adjacent slopes. Most of the timber was used for building local homesteads, fences, cabins for miners and trappers, and firewood. Later, when the orchard industry was flourishing in the valley, timber was needed for boxes and palettes. Trees were mostly removed by horse and wagon or floated down the river. No records exist of the amount or location of timber removed before the development of the Forest Reserve.

Truck logging began in 1931, after the road through Horseshoe Bend was improved and access by truck extended up the Naches valley. This improvement allowed a greater volume of timber to be removed. Most of the private timber land below the Forest Reserve was completely logged by 1944. Truck logging also led to the need for road improvements. Through the 1970s, selective-cut sales were extended throughout the mainstem valley and lower portions of the tributary drainages below Jungle Creek. Between 1963 and 1975, 17 percent of the harvestable acres of the Little Naches River basin were harvested. Commercial thinning and high grading on overstocked stands started around 1975.

The first clearcut sales were made in the lower basin of the Little Naches River basin. In 1975, partial cuts were extended into the area above Jungle Creek and the South Fork in both the mainstem valley and tributary slopes. From 1975 to 1985, harvesting was extended throughout the basin, including the headwater areas of the South Fork, Middle Fork, Sand Creek, and Matthew Creek. Clearcuts on the private checkerboard lands also started in 1975. By 1985, about 26 percent of the harvestable acres in the basin had been cut, by 1990 32 percent, and by 1992 35 percent.

The recreational patterns that developed in the Naches River basin were largely determined by the road and trail systems and their continued expansion and improvement. Early recreation was limited to picnicking and camping in the summer season when trails were passable, but became a year round pursuit as trails and roads improved. In the late 1800s, camping and picnicking along the alluvial flats were the first major recreational usages, followed in popularity by foraging for berries and fishing and hunting by horseback in the upper elevations.

By the 1950s, off-road uses had become popular, and they continue to be significant today. Back country camping and fishing is popular, but car camping along the edges of the river remains both the most extensive recreational use of the area, and possibly the most disturbing to riparian vegetation and stream bank erosion. Favorite camping areas have become compacted and devoid of understory vegetation, leading to increasing runoff and weakening root strength. At trail and road crossings, streambanks have become eroded. Also, to protect campgrounds from being eroded as the stream shifts its course, riprap and other channelization practices have been used.

To complicate matters, evidence exists of an extensive and extremely hot wildfire around 1850. This fire covered much of the northwestern portion of the basin from Crow Creek to the Middle Fork and two-thirds of the mainstem valley (Gossett 1979, Plummer 1900, Uebelacker 1980). Coupled with various land-uses, this event could have had long-term and cumulative effects on the stream network and forest composition. In this area, heavy sediment input to the tributaries and mainstem could help explain the sparse riparian vegetation and braided pattern of the mainstem channel in unconstrained areas. Presently, none of this area has been harvested and the upland forest stands are of the dense, mature type rather than old growth.

Changes in stream habitats (1935 to 1992)—From 1990 to 1992, the Pacific Northwest Research Station, in cooperation with the University of Washington and the Wenatchee National Forest, resurveyed over 80 km of historically surveyed tributary streams in the Yakima River Basin (U.S. Bureau of Fisheries, 1930s and 1940s). The resurveys included the Little Naches River, Rattlesnake Creek, and the American River of the Naches River Basin, and Taneum Creek. Taneum Creek, near Ellensburg in the Upper Yakima basin, is an example of a basin that experienced early grazing and timber harvest affects common to the upper Yakima drainage. The results from these resurveys, conducted from 1990 to 1992, indicate that pool habitat has increased in both managed and unmanaged portions of the Yakima River basin (McIntosh and others 1993, Smith 1993). Over the same period, the dominant substrate has shifted from gravel to coarser rubble and fine particles in Taneum Creek and the Little Naches River, but remains the same in Rattlesnake Creek. More detailed results on habitat changes in the Yakima Basin are presented in Smith (1993) and McIntosh and others (1993).

In 1990, the University of Washington initiated the resurveys and intensive studies of changes in stream and riparian habitats in the Little Naches River Basin (Smith 1993). The initial hypothesis was that pool habitats of streams had declined between 1935 and 1990. The 1990 resurvey indicated that the frequency of large pool habitat had in fact increased from 1.7 to 4.6 /km, and substrate composition had become coarser. The percentage of spawning size gravel for salmon was reduced by 50 percent throughout the mainstem channel. In addition, fine sediments (> 6 mm) had increased to 6 percent throughout the mainstem of the river (Smith 1993).

These results, along with anecdotal information from the 1935 survey, suggest that pool habitat had already been significantly degraded by human disturbance by 1935. Furthermore, although an increase was shown in 1990, pool habitat abundance and quality is still below present Wenatchee National Forest standards of one primary pool/three bankfull channel widths. Because much of the mainstem is constrained, this system may lack the capacity for an abundance of large pools, especially in the lower reaches. Channels constrained between valley walls can have more high-gradient channel units, such as boulder cascades (Grant 1987) except at meander bends, where large pools may form and persist (Lisle 1986). For drainages like the Little Naches River, current Forest standards may need to be revised and rehabilitation efforts to create large pools should be reconsidered.

In the constrained reaches of the Little Naches River, repeated scouring of the channel bed has coarsened the substrate and increased the exposure of bedrock, creating more frequent and larger pools. Roads and riprap have greatly confined the main channel, magnifying the effects of scour at high flows and the displacement of streambed substrates. The 1990 survey indicated that the majority of pools were bedform scour pools controlled by large substrate and bedrock.

The increase in percent fines (< 6 mm) in the Little Naches, along with the high degree of embeddedness, suggests that fine sediment has increased since 1935. At the same time, large rubble also increased significantly, now comprising almost 50 percent of the surface substrate. When other roughness elements are lacking (such as large woody debris and riparian vegetation) large rubble becomes an important pool-forming component. If the substrate is heavily armored and embedded, however, the habitat capacity of large substrate may be reduced. Furthermore, armoring the bed promotes bank erosion and impedes pool development through reduced bed scour. In the Little Naches River, armoring, through embeddedness (> 30 percent embedded for over 50 percent of the channel) of fine sediments in large rubble and medium rubble substrates, appears to have the long-term effect of reducing channel diversity and roughness. Where increased deposition of fines occurs in interstices of large streambed substrates, the effect may be a delay in the onset of bed movement during large flows, which in turn influences channel dimensions (Beschta and Platts 1986). This aggradation of fine sediments could also increase the effectiveness of moderate discharge rates to transport gravels and small rubble (Lisle 1982), therefore altering or eliminating spawning beds.

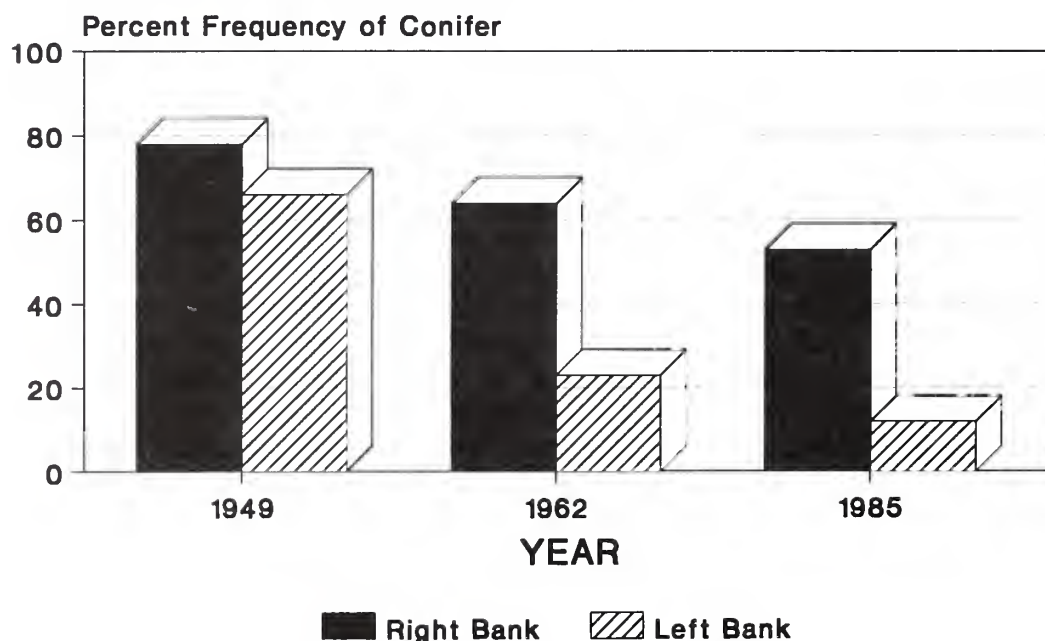
Conditions of the current stream habitat and those of riparian vegetation along the mainstem of the Little Naches River suggest possible lower riparian buffering capacities against stream flow and erosive processes. In arid eastside river basins, riparian areas can be limited to narrow strips along stream channels. In these areas, soil organics can be poorly developed and highly erosive. Under such conditions, the growth rate of riparian and upland vegetation can be slow for desired timber or conifer species. As a consequence, regrowth of riparian vegetation and hydrologic recovery (Sidle and others 1985) after disturbances of livestock grazing, recreation, and timber harvest may be slow. A brief synopsis presented below from the Little Naches River illustrates these trends in riparian vegetation and composition.

Changes in riparian vegetation—Although streams in the Yakima Region differ in habitat structures and hydrology, stream responses and damage from temporal and spatial patterns of land-use influences are generally similar throughout the region. Likewise, land use impacts on the health of riparian vegetation and its slow recovery may be similar throughout the region. Direct and indirect disturbances to riparian

vegetation include grazing, road construction, recreation, fires, and timber harvest. Responses in riparian ecosystems generally appear as losses in vegetation, shifts to younger conifers with greater portions of deciduous and shrub species, the narrowing or constriction of the riparian zones, and increased soil erosion (Gregory and Ashkenas 1990, Gregory and others 1991, Kauffman 1988).

The Little Naches can be divided into three general zones of effects. The lower mainstem, upper mainstem, and tributaries. The effect of grazing, fires, roads, recreation, and timber harvest act on these areas differently because of differences in valley geomorphology and the timing of the effects. The lower mainstem is naturally constrained by basalt bluffs except in a few areas such as Kaner Flats. Riparian vegetation is limited to small areas along the channel with some upland species extending to the channel margin. Trail and road construction further limit riparian development in the unconstrained areas and increase the amount of bare ground exposed to erosion—especially along the left bank, where the riparian area ranges from 28 percent to 56 percent of the channel length along the river's mainstem channel (Smith 1993). Conifers are dominant, but diminishing, and the age class has become younger over time. Between 1949 and 1985 the most dramatic changes occurred on the left side of the river. The percentage cover of conifers in the riparian area decreased from 66 percent in 1949, to 23 percent in 1962, and 12 percent in 1985 (fig. 6). In these riparian assemblages, the proportion of mature and old-growth trees decreased from 67 percent in 1949, to 13 percent in 1962, and then 50 percent in 1985. On the right side of the river, the percentage decline in conifers was less dramatic, from 78 to 53 percent. Here, the proportion of mature and old-growth areas decreased from 56 percent in 1949, to 14 percent in 1962, and increased to 37 percent in 1985. Interestingly, on the left bank, the conifer forest was replaced by bare ground (28 to 56 percent) and mixed conifer and deciduous trees (fig. 7). On the right bank, the loss of conifer cover was replaced by a young mixed forest.

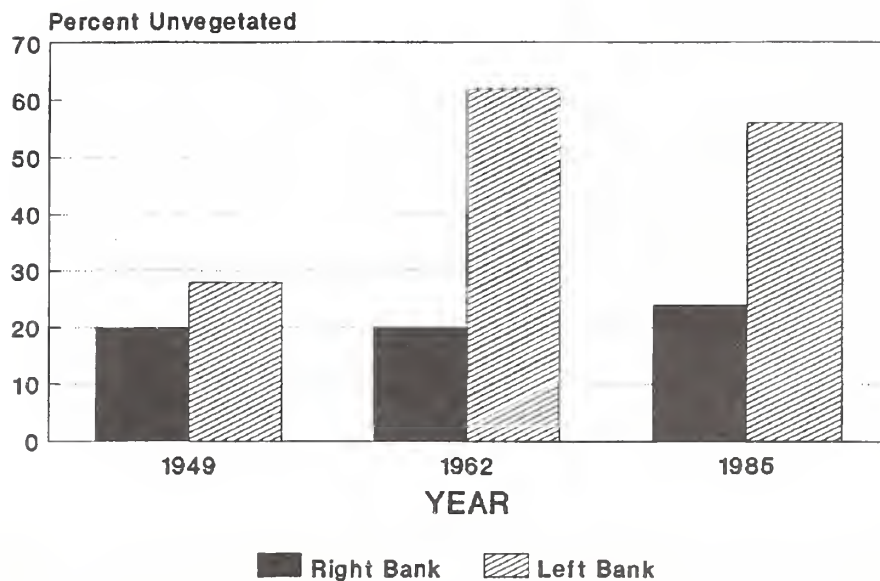
Percent Conifer in Riparian Area Lower Basin - Little Naches River, WA



Percent = % freq. of riparian increments classified as conifer

Figure 6. Percentage of riparian area in conifer vegetation in the lower mainstem of the Little Naches River, WA. Left and right banks are assigned by looking downstream. Data taken from aerial photos and expressed as percents of the channel length in mainstem (Smith 1993).

Proportion of Riparian Area Unvegetated, Lower Mainstem - Little Naches River, WA

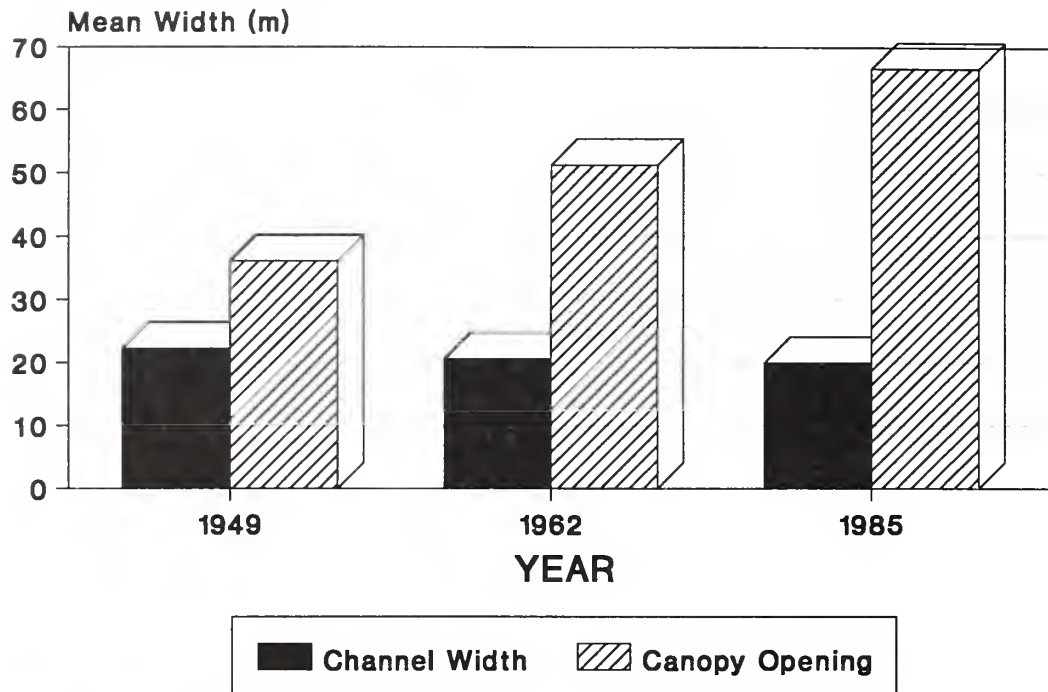


Left & right bank looking downstream

Figure 7. Percentage of unvegetated riparian area in the lower mainstem of the Little Naches River, WA. Left and right banks are assigned by looking downstream. Data taken from aerial photos and expressed as percents of the channel length in mainstem (Smith 1993).

The changes in percentage and age structure of conifers, increases in bare ground, and increases in riparian canopy openings adjacent to the stream channels suggest that the effects of different disturbances were combined. These disturbances include selective harvest in the 1960s, subsequent flood events in 1964 and 1977, increased recreational use, and reconstruction of the main road along the stream. Measurements of riparian canopy opening over the last 40 years show a significant increase in the mean canopy opening from 36 m in 1949 to 67 m in 1985 (fig. 8).

Active Channel Width & Canopy Opening Lower Mainstem - Little Naches River, WA

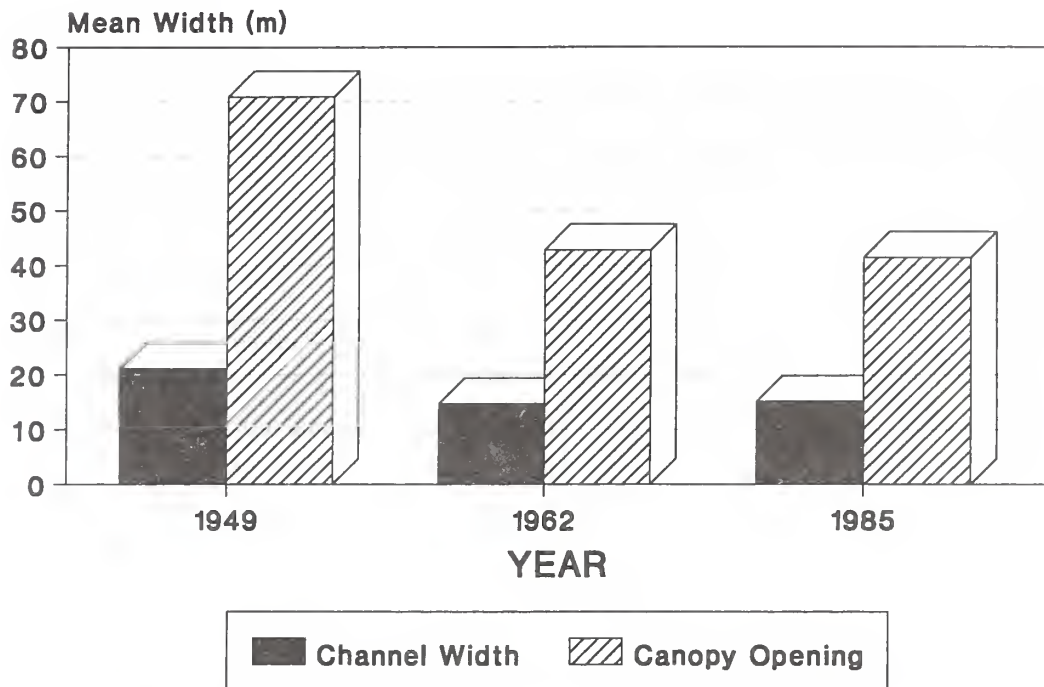


Data from Aerial Photos

Figure 8. Mean active channel width and canopy opening width in the lower mainstem Little Naches river, WA. Active channel width is defined as the proportion of the channel bottom influenced by bedload transport. Data are from aerial photos (Smith 1993).

The upper mainstem is less constricted than the downstream, with larger areas of open alluvial valleys. The riparian zone has potential for greater development as the channel meanders across the valley through well-developed soils. Both the riparian and stream habitat characteristics of this area are prime indicators of past patterns of land-use and disturbance. In general, the degradation of riparian vegetation and stream habitats by grazing most likely persisted through the early 1940s. The following 20 to 35 years was a hiatus from intensive land-use disturbance, which allowed the channel to accommodate excess sediment deposited over time and the riparian vegetation to grow and mature. Both mean canopy opening and mean active channel widths decreased 30 to 40 percent from 1949 to 1962 (fig. 9). The delay of harvest until 1975 in this area could explain the lack of change in canopy and active channel widths from 1962 to 1985. These "stable" stream and habitat conditions persisted, despite the effects of the 1964 and 1977 large flood events, and concurrent increases in road building and timber harvesting throughout the headwaters and tributary valleys. The cumulative effects may not be evident now.

Active Channel Width & Canopy Opening Upper Mainstem - Little Naches River, WA



Data from Aerial Photos

Figure 9. Mean active channel width and canopy opening width in the upper mainstem Little Naches river, WA. Active channel width is defined as the proportion of the channel bottom influenced by bedload transport. Data are from aerial photos (Smith 1993).

The riparian vegetation is still dominated by conifers (34 to 70 percent), but the age class has shifted from old and mature trees to young and small trees. In addition, conifer decreased more than 50 percent on the left bank because the main road was extended through this section (fig. 10).

Percent Conifer in Riparian Area Upper Mainstem - Little Naches River, WA

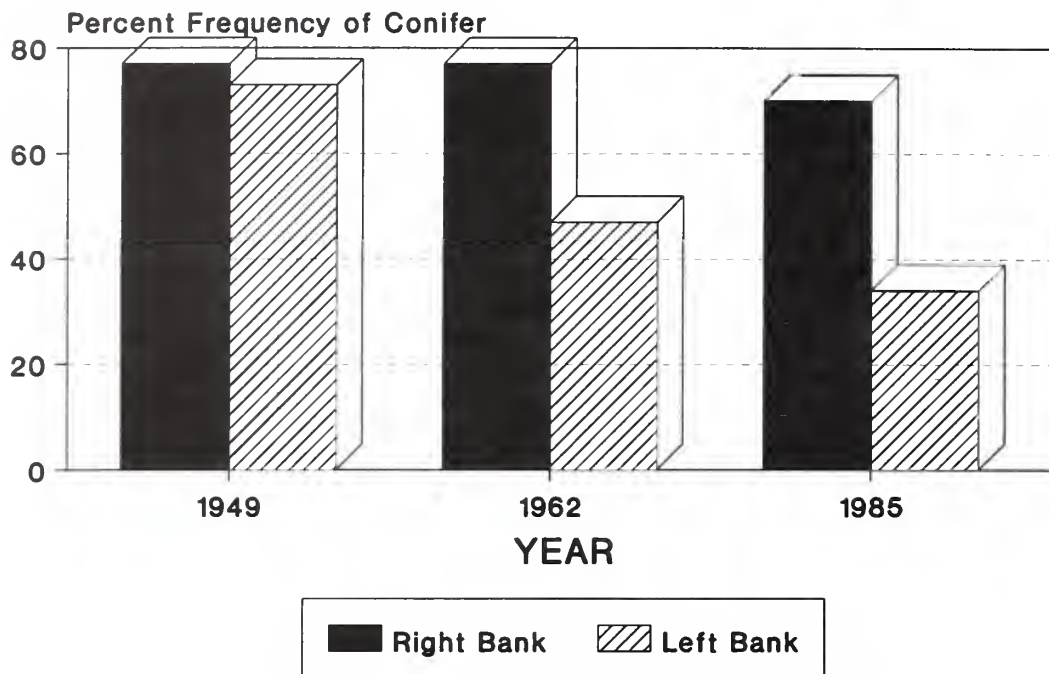


Figure 10. Percentage of riparian area in conifer vegetation in the upper mainstem of the Little Naches River, WA. Left and right banks are assigned by looking downstream. Data collected from aerial photos and expressed as percents of the channel length in mainstem (Smith 1993).

Conclusions and recommendations—The tributaries of the Little Naches River are conduits for sediment transport to the mainstem. They can either buffer the affects of land uses in the headwaters or they transport those effects to the lower drainage. Certain tributaries were more heavily used in the grazing era and show the effects in the photo record. Others were not affected greatly until the onslaught of road construction and timber harvest. Furthermore, because these activities have been occurring for only a relatively short time (10 to 15 years), we may not be seeing the full effect at present. Further analysis of aerial photos and survey data is needed to assess changes to the riparian areas in the upper tributaries.

The changes in the riparian zone in the Little Naches River have implications for the health of the watershed. Loss or constriction of the riparian area reduces the buffering by riparian vegetation of streams from upland effects (such as, road use and timber harvest) that cause soil erosion and produce fine sediments. The increasing percentage of bare erodible area weakens the resistance of the channel banks to erosion and also indicates a general lack of overhanging vegetative and cover for fish. Increasing canopy opening allows more solar radiation to elevate water temperatures during summer low flow. The 1990 survey data showed that water temperatures in the mainstem Little Naches commonly exceeded the Forest standard of 61° F (Ehinger 1990). Finally, the reduction of the proportion of conifer and mature conifer implies an increasing deficit of high-quality large woody debris available to the stream in the future.

Although pool habitats increased over time in the Little Naches River during the last 55 years, other habitat components critical to abundant and healthy spawning and rearing habitats have been reduced. Off-channel habitat, riparian cover, riparian edge and channel complexity, and spawning gravel decreased over time. During this period, substrate embeddedness, percentage of fines, and water temperatures were elevated. Without proper management and protection, these habitat conditions could degrade further with planned timber harvest and present recreational pressures. Furthermore, the condition of the riparian zones buffering the stream may be inadequate to mitigate the land-use effects over the next decade.

A period of relative inactivity in the tributary portions of the Yakima Basin, followed by much later entry for timber harvest, may explain some of trends in improving stream habitat. These trends must be viewed in the perspective of current standards for pool habitat, however. None of the streams we have surveyed comply with current Forest Service standards for pool habitat. Although the trend in improving habitat is encouraging, the stream habitats we surveyed are still in poor condition. Furthermore, given the late entry for timber harvest, stream habitats may not yet be fully expressing the cumulative effects of harvest activities. Management priorities for stream protection as well as enhancement projects should emphasize monitoring to better define trends in habitat changes.

Grande Ronde River (Eastern Oregon)

Land uses and changes in stream habitats—In 1990, the Pacific Northwest Research Station conducted a study to examine how anadromous fish habitat had changed over time in the Upper Grande Ronde River Basin (McIntosh 1992). Using a U.S. Bureau of Fisheries stream survey from 1941 (Parkhurst 1950, Rich 1948), the Pacific Northwest Region documented a 60 percent loss in pool habitat, along with high concentrations of fine sediments throughout chinook salmon spawning habitat. At the time of the 1941 Bureau of Fisheries survey, the upper Grande Ronde River basin had already experienced considerable human-induced disturbance. Complementary research on wilderness streams in the Columbia River Basin has shown that pool habitat has improved or stayed the same over the same period (McIntosh and others 1993, Sedell and Everest 1990). McIntosh (1992) demonstrated that anadromous fish habitat in the Upper Grande Ronde Basin has been severely degraded by land-use activities over the past 50 years.

When the loss of pool habitat is added to the previously documented (James 1984, ODFW 1987, NPPC 1990) problems of highly degraded riparian habitat and extreme water temperatures, both winter and summer, the condition of anadromous fish habitat becomes much more critical. In addition, current stream surveys from the Wallowa-Whitman National Forest indicate that more than 70 percent of the stream miles in the Upper Grande Ronde River basin fail to meet current Forest Plan standards for fine sediments, stream shading, and water temperature, and much of the stream system is lacking in large woody debris. The changes since 1941 indicate that the cumulative effects of land use have caused extreme degradation of stream and riparian habitat on the scale of a large watershed. Rearing habitat for juvenile fish, resting habitat for migrating adult fish, and refugia for adults and juveniles from catastrophic events—such as drought, fire, and winter-icing (Sedell and others 1990)—has been severely reduced by loss of pool habitat. Susceptibility to disease and predation is likely to have increased because fish are crowded into fewer areas.

Surface fines are high (> 20 percent) throughout the headwaters of the Upper Grande Ronde River. The measured amounts remain above those currently recognized by the Forest Plan as necessary for high egg survivability (< 20 percent surface fines). This area represents the primary spawning habitat for the spring chinook stock in the Upper Grande Ronde, currently listed as threatened under the Endangered Species Act. Substrate composition is important in influencing the quantity and extent of spawning habitat and both provides summer and winter cover for juvenile fish and influences aquatic biological production. A considerable body of literature has demonstrated the detrimental effect of fine sediments on salmonid reproduction (Chapman 1988, Everest and others 1987). The extremely low return of adults (1990 estimates of < 100 fish) suggests that silt-laden spawning habitats, as well as ocean-based commercial fisheries, depress spring chinook runs in the upper Grande Ronde.

Land-use records indicate that domestic livestock grazing, splash dams and associated log drives, and mining, significantly affected anadromous fish habitat before 1941. Stream channelization—feasible because heavy equipment was available after World War II—also greatly reduced stream habitat diversity throughout many portions of the upper Grande Ronde. Timber harvest and road construction have increased substantially since the 1950s becoming the dominant land-use activities in the upper Grande Ronde River basin (fig. 5). The legacy of historical land uses, coupled with the effects of current upslope management practices, are pervasive and continue to forestall recovery.

Land-uses and changes in streamflows—Analysis of long-term streamflow and climate records indicate significant changes since 1904. Base flow has increased, and annual and winter precipitation, along with snowpack, have decreased. The timing of peak discharge appears to have shifted to one month earlier in the year. The near doubling in base flow while precipitation has declined suggests that the increase is not due to climate. The altered base flow regime may be the result of extensive defoliation from insect infestations and timber harvest. The reduction in moisture lost to transpiration, resulting from decreased leaf area by insect defoliation and timber harvest, could result in more precipitation being retained as soil moisture, eventually being released to the stream channel through subsurface flow. The higher base flow did not translate into increased annual discharges. Base flow may be more sensitive to increased subsurface flow than annual discharge because base flow is less than 3 percent of the annual water yield.

Change in the timing of peak discharge to one month earlier in the year could also be a result of land-use practices. Research in western Oregon has shown that snowfall accumulations are greater in the clearcuts and that they melt earlier because of increased exposure to solar radiation (Harr 1983). The high rate of timber harvest in the upper Grande Ronde River basin may have created similar conditions.

The shift in timing of peak flows may have implications for the emigration of salmon smolts from the basin because their migration is timed largely to peak flows. If the smolts are forced to migrate earlier, they may not be physiologically ready; or if they do not migrate, they risk leaving later, when conditions may be uncertain. The migration of smolts is a highly evolved process that represents a critical juncture in the life history of anadromous salmonids.

Conventional wisdom holds that the rearing capability of streams in eastern Oregon is limited by base flow. The increased base flow in the upper Grande Ronde River indicates there may be sufficient summer flow, but habitat conditions of both stream and riparian ecosystem cannot function together and adapt to changes in flow conditions. For example, in-stream habitats (pools and riffles) and riparian plant assemblages that have been altered by different land and water uses may not be able to utilize increased base flows (Elmore and Beschta 1987, Sedell and Beschta 1991).

Restoration efforts—We recommend that historical perspectives of cumulative land- and water-use effects on stream and riparian ecosystems within different river basins of eastern Washington and Oregon be used to provide useful time frames for identifying desired conditions and opportunities for restoration. For example, for the Grande Ronde River, pool habitats are not distributed evenly along the stream network, but tend to be grouped in patches. The majority of the pool habitat, both historically and currently, is found in unconstrained reaches of streams, providing the geomorphic context to habitat distribution. In 1941, these unconstrained reaches represented 40 percent of the stream length, but contained 69 percent of the pool habitat in the Upper Grande Ronde River. By 1990, these four reaches held 48 percent of the pool habitat.

Unconstrained reaches are the most dynamic, complex, and productive portions of the riverine environment (Gregory and others 1991, Sedell and others 1990). These complex and productive habitats are the result of frequent interactions between the channel and the associated floodplain and riparian vegetation. Research in western Oregon has shown that unconstrained reaches have the highest biotic productivity (Gregory and others 1989, Lamberti and others 1989, Moore and Gregory 1989).

To expedite recovery of stream and riparian habitat, thus improving anadromous fish habitat, recovery efforts for the near term should be focused on unconstrained reaches. These areas should exhibit fast rates of physical and biological recovery. Efforts should focus on restoring and enhancing the natural processes that cause these reaches to be so highly dynamic, complex, and productive.

Restoration of stream and riparian habitat in the upper Grande Ronde River basin will require changes in upland management practices and a long-term commitment to good watershed stewardship. A framework for this stewardship has been developed in the upper Grande Ronde River Anadromous Fish Habitat Protection, Restoration, and Monitoring Plan (Anderson and others 1992). In the near term, anadromous fish stocks need relief from highly unfavorable rearing and spawning conditions. The emphasis of management should be a focus on accelerating recovery through sound and biologically defensible methods. These efforts should be concentrated on those areas most important to the rearing and spawning of anadromous salmonids and should in no way forestall the long-term recovery of the upper Grande Ronde River basin.

John Day River (North Central-Oregon)

Land-use history—The John Day River has a drainage area of about 21,000 km² comparable in size to the State of Massachusetts. Historical accounts of the John Day River describe its banks as covered with dense growths of aspen, poplar, and willow. Anecdotal reports, such as the inability of Peter Skene Ogden, a fur trader during the 1820s, to ford horses across the river near the town of Prairie City during summer low flows, suggests that the hydrograph has changed substantially (Hudson Bay Historical Society 1950). Beaver were also reported to be abundant. Historical photographs of the river at Picture Gorge show cottonwood galleries a quarter mile wide, where only a few trees now exist (Bancroft Library, University of California, Berkeley). Before settlement, the basin supported substantial runs of spring and fall chinook salmon and summer steelhead. Currently, fall chinook appear extinct and spring chinook runs range from 2000 to 5000, and steelhead from 15,000 to 40,000 fish (Northwest Power Planning Council 1989).

The first settlement in the basin came when gold was discovered in 1862. Most of the mining was in the upper mainstem of the John Day near Canyon City, the Middle Fork of the John Day near Galena, and the North Fork of the John Day near Sumpter, Oregon. Placer mining—and later, dredge mining—drastically changed the character of the landscape. Dredging disturbed riparian vegetation, overturned bottom substrates, channelized streams, and devastated spawning gravels with the deposition of fine sediments. The legacy of this period remains today, with many kilometers of dredge spoils, especially in the North and Middle Forks of the John Day. Settling ponds in the upper North Fork remain a source of toxic heavy metals (Hudson Bay Historical Society 1950). Streamflow in several creeks in the Malheur National Forest goes subsurface because of the disruption of the stream bed.

During this same period, irrigation and logging began. The first sawmill was established in 1862 (OWRD 1986). Cattle grazing operations began during the 1860s, primarily near Lower Rock Creek and the towns of Clarno and Shaniko. Sheep were introduced in the 1880s and, by the 1900s when the railroad was established, Shaniko became one of the world's largest shipping centers of wool. Early aerial photographs by the Oregon Historical Society show the hillsides so thick with sheep that, on first glance they appear to be snow drifts. Throughout this period, grazing intensity was high. For example, Alder Creek, a small watershed of 89 km², had heavy grazing by 30,000 sheep over a few years. Soon after sheep were introduced, cattle followed. The introduction of exotic herbivores was especially damaging because the vegetation of eastern Oregon and Washington evolved without large, grazing herbivores (Mack and Thompson 1982). The native bunchgrasses were displaced by exotic flora, such as cheatgrass.

Before the settlement by Euro-Americans, fire return intervals ranged from 45 to 75 years in Wyoming big sagebrush communities, and 10-15 years in mountain big sagebrush, ponderosa pine associations (J. Boone Kauffman, pers. comm.). Grazing, fire suppression, and the introduction of exotic plants have greatly altered plant community composition and disturbance cycles. Natural fire cycles have been disrupted, thereby changing nutrient cycling and patterns of plant succession. The present plant communities bear little resemblance to the original flora. Undoubtedly, these changes have altered the natural hydrologic cycle.

Native plant communities changed as a result of the expansion of western juniper and sagebrush, and exotic plants and species not palatable as forage began to crowd out native bunchgrasses. The present plant communities are less subject to the low-intensity range fires of the past, which reinforces the present plant assemblage structure (J. Boone Kauffman, pers. comm.). The expansion of juniper is especially noticeable when historical and recent photographs of specific locations are compared. For instance, aerial photographs taken of the area surrounding John Day and Canyon City show that juniper was confined to small pockets in 1939 (Oregon Water Resources Department 1986). Photographs taken in 1986 show that junipers now dominate the landscape. Western juniper can intercept and transpire as much as 25 percent of the precipitation. Junipers in central Oregon range from 186 to 421 trees/acre. James R. Sedell (pers. comm.) estimates that for a 400,000-acre watershed, with 250 junipers per acre, water lost through transpiration could be equivalent to 3500 to 7500 cfs per day.

The Blue Mountain Forest Reserve was established in 1906 and, by the 1920s, timber harvest had become an important activity in the basin. Currently, timber harvest is the major land-use activity in the Ochoco, Umatilla, and Malheur National Forests. The historical record indicates that timber harvest steadily increased until about 1950, and has remained at these rates (fig. 11).

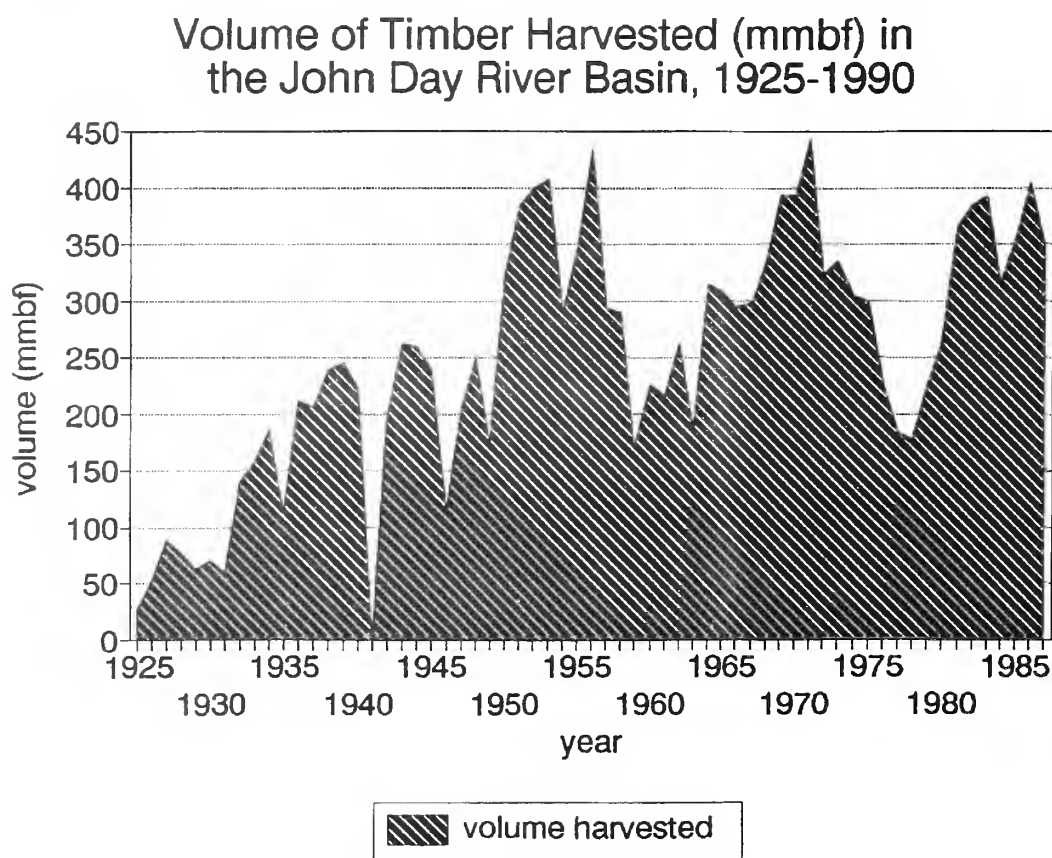


Figure 11. Volume of timber harvested in the John Day River basin, 1925-90 (Oregon Department of Forestry 1990).

Land uses and changes in stream and riparian ecosystems—The combined effects of all human activities have dramatically changed the riverine system of the John Day basin. The hydrograph has changed significantly, with base flows increasing in all managed watersheds and remaining the same in the wilderness drainage (McIntosh and others 1993). This finding suggests that the headwaters have lost riparian and stream habitats and their capacity to store water for release during the low-flow periods of summer (McIntosh and others 1993). No direct proof has been found, but flash floods and their subsequent effects, appear to be more frequent and severe. Recent research has indicated that the effects of flash flooding are far more deleterious on fish communities in highly altered stream reaches than those in more natural conditions (Pearsons and others 1992). Turbidity in some parts of the basin, such as Cottonwood Creek, a tributary to the North Fork, is notoriously high after storm events. The resulting siltation of stream beds results in decreased aquatic insect production and degraded spawning gravels.

The riparian canopy is completely gone in many parts of the watershed with less stream cover and shading than the recommended 75 percent closure (Li and others 1992). A study of several small watersheds indicated the effect on riparian vegetation can be severe where the riparian habitat has been altered through human-caused activities, such as sheep and cattle grazing (Pearsons and others 1992). Severe increases in water temperatures, both summer and winter, are critical limiting factors for salmonids over many portions of the watershed (Adams and others 1990, Li and others 1992, Li and others, in press). Tiedmann and Higgins (1989) found that the short-term threshold for rainbow trout (23.8°C), as recommended by U.S. Environmental Protection Agency, was regularly exceeded in streams where experimental grazing was tested. They could not attribute this to grazing practices, however, Li and others (in press) found that daily temperatures regularly exceeded the upper incipient lethal temperature (26.5°C, Bidgood and Berst 1969) for steelhead trout in Rock, Mountain, and Alder Creeks, where the primary disturbance was cattle grazing.

Hypotheses have been advanced that the inland rainbow trout populations of the John Day basin are more adaptable to high temperature than other strains. Li and others (1992), however, found that rainbow trout selected cold-water habitats when the ambient temperature of the main stream approached 24°C. Interestingly, rainbow trout were rarely in cold-water habitats when the stream temperature was below 20°C. Cold-water refugia are critical in stream systems where temperatures regularly approach lethal heights (Berman and Quinn 1991). Unless maps of temperature microhabitats are described, inferences concerning temperature adaptability of inland rainbow trout may be misleading.

High temperatures can have several different effects in stream ecosystems. Fish can be subject to lethal or sublethal thermal stresses that impose severe metabolic costs. In the John Day basin, some stream reaches that exceed 32°C during the diel cycle in the summer are devoid of fish (Li and others in press). Studies for the John Day using the metabolic model of Wurtsbaugh and Davis (1977) suggest that the metabolic maintenance demand by juvenile steelhead increased 23 to 43 percent from the coolest to the warm stream reaches (Li and others 1992, in press).

The lack of thermal cover by riparian ecosystems in the John Day Basin also appears to affect fish food webs. Higher solar radiation at stream surfaces and benthic algal production can induce or alter the development of prey types that may or may not be available as fish food. (Tait and others, manuscript submitted). For example, in the John Day basin, standing crops of algae become higher in exposed reaches (no riparian cover) of streams because of light enhancement of primary production. The increased algal forage base for aquatic insects, however, did not translate into greater prey availability for the fishes. The algae supported additional invertebrate biomass comprised of large, stone-cased, caddisflies. These aquatic insects, because of their protective cases, were invulnerable to predation by fish.

Evaluation of habitat rehabilitation programs—Stream and riparian ecosystems of the John Day and other eastern Oregon watersheds have suffered from poor livestock and forestry practices (Beschta and others 1991, Kauffman 1988, Kauffman and Krueger 1984). Although most of the evidence is anecdotal,

conventional wisdom holds that the carrying capacities of these streams for salmonids have been greatly diminished. As a result, large sums of money have been invested in habitat restoration in eastern Oregon as part of the long-term plan to restore anadromous salmonids in the Columbia River System. For example, the Bonneville Power Administration spent about \$6,000,000 in the John Day basin (Rick Stoots, pers. comm.). Unfortunately, no funds were allocated for monitoring projects because evaluation was not considered in the design of restoration work. The result of this policy is that how effective various restoration efforts are is unknown.

Despite not having monitoring data from before or after enhancement projects, three evaluations of habitat rehabilitation efforts have been conducted. These evaluations include a bioeconomic study of habitat restoration (Adams and others 1990); a study of log sill/log weir emplacements in Camp Creek of the John Day basin (Li and others 1992); and a field review of stream-enhancement projects in eastern Oregon (Beschta and others 1991). Adams and others (1990) found that different stream factors limited the capacity of habitats in different physiographic settings. They suggested that increased summer streamflow and reduced temperatures could increase fish use of habitats. Li and others (1992) found that the installation of log weirs in Camp Creek did not address the critical problem of water temperature, the major limiting factor there. The objective of the habitat-enhancement program was to increase the number of pools in a riffle-dominated system. The effect of installing about 280 log weirs (at about \$750 per log weir) was to increase pool volume by 4 percent. Moreover, increased rainbow trout density and use of habitat were insignificant. Li and others (1992) demonstrated that variations in water temperatures caused fish populations to be food limited.

The evaluation of habitat rehabilitation projects by Beschta and others (1991) used visual assessments of the status of riparian vegetation and geomorphic conditions in stream channels. They concluded that efforts to rehabilitate stream habitat on a site-specific basis without examining the entire river and riparian landscape contributed to the lack of success of many projects. Beschta and others (1991) suggest that the most effective means of restoring habitat is to permit natural riparian plant succession to occur and to reduce the most detrimental source of disturbance, livestock grazing. They suggest that cattle exclosures can be excellent tools for habitat restoration. Hard structure emplacements in stream channels appeared to create minimal benefits at the cost of disrupting the natural processes of the stream channels and interactions with floodplains.

All three studies indicate that most of the enhancement programs do not help address the basic causes of habitat changes. Furthermore, evaluation of current habitat rehabilitation programs, because basic physical and ecological information are lacking, could be creating the illusion that habitat restoration can be quickly accomplished through technological means. For enhancement programs to succeed, they need better landscape information about habitat structure and function. These data can be obtained through long-term monitoring programs. Finally, restoration efforts need to give careful consideration to temporal scales of salmonid life cycles, fish relations to stream-habitat changes and riparian plant succession patterns.

SELECT STREAM AND WATERSHED MANAGEMENT APPROACHES

Instream Flow Incremental Methodology (IFIM)

Effect of water diversion on stream flows and salmonid habitats (Methow River, WA)—A major historical and contemporary water issue in eastern Washington and Oregon is the effect of water diversion on river flows, habitats, and salmonid populations. An excellent case study of the problem is the Methow River basin. Wild anadromous fish populations of the Methow River are depressed. The major factors limiting salmonid production include dams on the Columbia River, seasonal losses of water in the tributaries, and historical cumulative effects of past land and water uses. Although the nine dams on the Columbia River currently limit fish passage and create other survival problems (such as predation and temperature) the Methow River was completely blocked from 1912 until the 1930s by a hydroelectric dam at Pateros near the river mouth. The Pateros dam caused the extinction of a coho salmon run and perhaps other salmonids. After the dams' removal, the Methow River was planted with hatchery and trap-release salmon and possibly colonized by straying Columbia River fish. Historically and today, irrigation withdrawals during low-flow periods also limit salmonid production in the river. Water withdrawals are considered detrimental because fish production in the Methow River appears naturally limited by low flows, losses of water to groundwaters (dewatering) in porous substrates, and high-gradient and erosive conditions in tributary watersheds. Current anadromous salmon runs include summer steelhead, spring chinook, summer chinook, and fall chinook. Resident fish populations include rainbow, cutthroat and brook trout, bulltrout (or dolly varden), whitefish, suckers, and sculpins. Information sources and additional data about salmon population sizes, limiting factors, management goals, life history, and the timing and location of spawning include the Methow and Okanogan Rivers Sub-basin Salmon and Steelhead Production Plan (Washington Department of Wildlife and others 1989); Kohn (1987, 1988, 1989); Edson (1990); Meekin (1991); and Langness (1991).

The Methow River case involves recent interactions of the valley's Pilot Planning Project (PPP). The PPP includes different caucuses (business, agricultural, recreational, environmental) comprised of the local residents and other key representatives such as the Methow Valley Irrigation District, Okanogan County officials, Washington State Department of Ecology, and the Yakima and Colville Tribes. Representing Washington State, the Department of Ecology is responsible for reviewing previously adopted minimum instream flows and assessing the effect of new water-right appropriations on salmon habitat. Since 1983, the Department of Ecology has used the Instream Flow Incremental Methodology (IFIM) to provide information for adoption of minimum instream flows (Bovee 1982, Milhous and others 1976, 1989). The IFIM defines fish habitat in terms of water depth, velocity, substrate, and cover. Participants in the Department of Ecology's Methow project include the Washington State Department of Fisheries, Washington State Department of Wildlife, the Yakima Indian Nation, Colville Confederated Tribes, Okanogan County, and U.S. Fish and Wildlife service.

Today, a majority of the PPP's caucus members and the irrigators disagree with the findings of the IFIM study of minimum instream flows (Caldwell and Catterson 1992). The major concerns are IFIM assumptions pertaining to where and at what times water is withdrawn and where the water goes when irrigation diversions cease. Some members believe that all the water returns to the river and others assume that none of the water gets back to the river. The Department of Ecology suggests that a solution to water losses during irrigation might be to adopt conservation strategies for agricultural uses. An additional concern of the caucus members is that the IFIM study prompted the Yakima Indian Nation to request a moratorium on new wells in the Methow Valley. The Department of Ecology study has not set a optimum flow regime for the Methow River because a consensus is needed by State and Federal agencies and the tribes on the effects of assessed environmental conditions on fish.

The Department of Ecology maintains that setting minimum instream flows will preserve fish habitat during low-flow periods. The most important flows are during the low-flow period of August to October when adult salmon return to the river. The Department of Ecology recommends that future minimum instream flows for the Methow River basin need to include the relative importance of different river reaches, salmon species and life-stages and the peak weighted-usable-area (index of fish habitat). Such information is needed because different fish species and life-stages co-exist in the river and each has a different flow requirement. The Department of Ecology suggests that minimum instream flows also need to consider those necessary for incubating salmon eggs, smolt out-migration, adult fish passage to spawning grounds, and the prevention of stranding of fry and juveniles. Specific environmental factors should also be considered: water temperature; water quality; and sediment loads (Caldwell and Catterson 1992).

In the Methow River basin, some of the concerns were discussed in the EIS for the Early Winters Alpine Winter Sports Study (Okanogan National Forest 1990). Little attention, however, was given to potential cumulative effects of proposed land uses on the quality of surface water runoff, groundwater, pollution, and water allocation on river and riparian ecosystems. Future effects included expansion of a proposed ski area, land exchanges, and practices such as urban storm runoff and golf-course fertilization, waste treatment, waste disposal, and air pollution through precipitation inputs. Together, these actions through time could have been highly detrimental to the water quality and health of river and riparian ecosystems and their wildlife and anadromous fish habitats.

The EIS (Okanogan National Forest 1990) recognized that the groundwater system of the Methow Valley, and its high hydraulic connectivity with surface waters function as the key component of the valley's hydrology, influencing seasonal streamflows. During the spring and early summer, the Methow River is an influent river and, for example, recharges the aquifer, but in the fall and early winter, the river is effluent—fed by groundwater discharge. The EIS points to the extreme importance of protecting surface waters and all groundwaters in significant hydraulic continuity with surface waters (Washington State Water Resources Act 1971, RCW Chapter 90.54), but gives minimal attention to the productivity of riverine and riparian ecosystems.

Recent research findings for the Flathead River in Montana have demonstrated the importance of hydraulically connected aquifers and channels to river ecology (Stanford and Ward 1988). The Flathead River has an extensive valley-floodplain aquifer and alluvial geomorphology that is very similar to the Methow Valley's. The floodplain, extending up to several kilometers from the channel, is hydraulically connected to channels and supports deep below-ground habitats (~ 10 m) penetrated by riverine animals. These animals and estimates of mass transport of nutrients from flowing groundwater habitats (hyporheic habitats, Stanford and Ward 1988) point to their extreme importance to the biotic productivity of the channel and riparian ecosystems. Underground waterways can serve as refuge for animals during time of drought or other stresses. In addition, the belowground habitats are commonly rich in bacteria that cycle nitrogen and other nutrients. These nutrients are in demand by both river and riparian organisms. The diversity of life is so great in these underground habitats that they may serve to help clean rivers of contaminants.

Our review for the Methow River suggests that the IFIM method's "instream perspective" does not adequately consider hydraulic continuity between groundwater and surface water and their relation to irrigation-canal flows. In alluvial river basins like the Methow River, glaciers left deposits of porous and permeable sands, gravels, and cobbles that form aquifers with a high degree of hydraulic continuity between groundwater and surface waters. Surface waters in the Methow River basin, as discussed above, are lost and gained during different seasons and in different reaches as the river flows downstream (Golder Associates 1991). Groundwater flows can reverse directions, causing water levels in wells to vary as flows change in the river channel (GeoEngineers 1990). Because of these geomorphic and hydrologic characteristics, much uncertainty exists as to where water goes when the irrigation diversions cease (Caldwell and Catterson 1992).

Additional information about these geomorphic features and flow regimes is needed to understand the relations of irrigation-canal flows to the discharge rates in the Methow River and to establish minimum instream flows to ensure the survival of fish eggs and juveniles in river reaches that dewater. Knowledge of these physical conditions is also central to determining water requirements for developing wells for drinking water, recreational, and commercial development and for protecting water quality from potential pollution from urban growth, agricultural activities, and landfill waste sites (Willms and Kendra 1990).

The pollution of groundwater by nitrogen could be a major worry in managing water quality in regions like the Methow Valley. The evaluation of pollution problems should take into account the chemical behavior of the mobile nitrate ion in groundwaters and the biological or chemical processes comprising sources and losses for various nutrients. For example, consideration should be given to processes relating to the formation and loss of ammonium. Ammonium usually cannot be considered a product of natural purification processes of surface and groundwaters, but as a contaminant resulting from practices such as urban-agricultural fertilization and cattle grazing. Ammonium is also a major source of nitrate.

Equivalent Clearcut Area Method (ECA): Hydrologic Effects of Logging

Forest managers have assumed that desynchronization or alteration of flows, caused by logging-induced diversity of snowmelt conditions, benefits soils and water resources (Harr 1987). This conception is based on studies in several regions of influences of timber harvest patterns on snow accumulation and melt (Halverson and Smith 1974, Troendle and King 1987). These findings may or may not apply in eastern Washington and Oregon, however, because of variable ecoregions, drainage basins, and hydrologic regimes that may be either beneficial or detrimental to streamflows. Harr (1987) points out that desynchronization or synchronization of flows depends on how flows combine from different runoff sources and tributaries to produce streamflow regimes in downstream reaches. For most situations east of the Cascade Range, little scientific information exists about how flows combine under natural conditions and little understanding of whether the effects on streamflow are beneficial or detrimental to streams. In reality, managers in many forested regions of eastern Washington and Oregon would have great difficulty evaluating the influences of logging-induced diversity of forest stands on snow and stream hydrologic responses (Wasson and others 1992). Available research on logged watersheds indicates that regardless of the changes in flow, assumptions cannot be made that logging patterns either desynchronize or synchronize flows or can be termed beneficial or detrimental to soils or water resources (Harr 1987).

Recent research findings in northern Idaho by King (1989), using the equivalent clearcut area procedure to evaluate the effects of timber removal by road building on streamflows, may have some applicability to portions of eastern Washington and Oregon. Forest Service resource specialists have used versions of this method to forecast streamflow responses to vegetation removal by timber harvesting, road building, and fire. The equivalent clearcut area procedure is designed to estimate the effects of past activities on streamflow and to develop timber harvest schedules of entry for future forest-management activities in third- and fourth-order watersheds (U.S. Department of Agriculture, Forest Service 1974, 1977). Equivalent clearcut area timber-harvest guidelines commonly place limits on expected increases in the monthly streamflow during spring runoff to prevent increases in high flows that may alter stream channels. Short duration high streamflows, however, are usually responsible for sediment bedload movement and suspended transport that change channel conditions (King 1989). King (1989) recommends that maximum daily streamflows would provide better stream protection than monthly increases in streamflow. Consideration to applying these maximum daily streamflows to smaller first- and second-order streams of headwaters should also be given, where large increases in maximum daily streamflows can occur after timber harvest. These recommendations recognize the importance of high-quality local streamflow and precipitation records for calibrating the equivalent clearcut area procedure.

The Watershed Cumulative Effects Analysis Model (KWCEA): Logging, Roads, and Soil Loss

Soil loss can be viewed as the major response of water and soils to problematic land- and water-use practices. The watershed cumulative effects analysis (KWCEA) model was designed to address many of these problems. The KWCEA model is an adaptation of the universal soil loss equation (USLE) and other watershed analytical procedures (Klock 1985). The model is designed for small watersheds (> 4000 ha) to assess the potential effects of forest practices on downstream aquatic ecosystems. The KWCEA model is also designed to facilitate the scheduling of future timber harvest and other forest management practices. The specific region for its application is the east side of the Cascade Range. The model provides a condition index for a watershed when a past-effects threshold has been reached and when significant downstream water-quality or ecosystem degradation has been documented; the index value suggests relative, cumulative effects and provides risk-rating levels of past, current, and future, forest management practices, and of worst-case conditions (Klock 1985).

Forest managers on the east side of the Cascade Range have found the KWCEA model useful because it was developed for the eastside (central Washington); contains scientifically based information; uses parameters that are easily attainable; allows risks to be compared between harvest alternatives; and facilitates scheduling timber harvests to minimize risks over time (Bill Garrigues, pers. comm.). The parameters of the KWCEA watershed cumulative-effects analysis value include: R = site erosivity energy potential based on precipitation; E = site surface erosion factor; S = slope stability factor; H = hydrologic sensitivity characteristic; T = topographic factor; A1 = total area of activity; and A2 = total area of watershed (Klock 1985). Applications include the evaluation of harvest units and road segments. Independent evaluations can be made for all the above parameters to derive a cumulative-effects risk value, ranging from 0 to 6, for each unit. Ratings less than 1.0 indicate a low cumulative-effects risk with a potential no greater than expected risk from natural hydrologic events. Ratings between 1.0 and 2.5 indicate a moderate risk, and ratings from 2.5 to 6.0 indicate a high risk.

Some of the limiting characteristics of the KWCEA model include the absence of, or need for mathematical validation of model behavior; statistical validation of risk values; improved data-compilation procedures; and the addition of predictive hydrologic and meteorological information. Some of these problems arise from the model's being developed for research on specific basins (Mullan and others 1992) and the basic short-comings of key components derived from the universal soil loss equation and other procedures.

The agriculturally based technology for predicting water erosion, known as the universal soil loss equation and its various versions have been the most common approach taken by management organizations over the past 20 years (Slaughter and Aldrich 1989), especially for predicting sheet and rill erosion. The procedure was derived from the basic equations of Zingg (1940) for the effect of slope length and steepness on erosion. The equation is an empirical approach with a lumped model structure that severely limits the potential for increasing accuracy. This "black box" model requires a large mass of data. The equation does not define separate factor relationships for the fundamental hydrologic processes of rainfall, infiltration, and runoff, and for the basic erosional processes of substrate detachment by raindrop impact and flow, or transport by splash and flow dynamics and deposition by flow. A new generation of water erosion predictive technology for use by the USDA Soil Conservation Service, Forest Service and the Bureau of Land Management is currently under development (Foster 1987).

Soil Compaction

Management agencies, such as the Forest Service and Bureau of Land Management, have developed procedures to organize soil compaction data related to timber harvest, road building, recreational activities in riparian areas, and related activities in watersheds. A common assumption is that soil compaction on 12 percent of total watershed area is a threshold for detrimental changes in streamflow. The origin of this threshold appears unclear and poorly documented. A recent synthesis of research findings (Harr 1980,

Harr and others 1975, 1979) shows a relation between flow increase and the amount of compaction and has demonstrated some major problems with using 12 percent as a threshold. Harr (1987) defined a curvilinear relation showing that flow increased exponentially with soil compaction, a relation that does not indicate a threshold. For example, a soil compaction of 12 percent corresponded with a 32 percent increase in peak flow, which indicates considerable adverse effects in streams. Such a relation suggests that different streams with varying channel geomorphologies would most likely be adversely affected by much lower flows than a 32 percent increase. These results indicate that the physical characteristics of a particular stream must be considered so as not to arbitrarily set the amount of compaction the same for all streams. The development of management thresholds and guidelines should include information about stream gradient, critical particle size, and channel geomorphology that relate to hydraulic principles and to the erosive power of the stream reach of interest (Grant 1987).

RECOMMENDATIONS

River Basin Perspectives of Cumulative Effects

Cumulative effects of land and water uses over the past century have greatly altered the health of river basins in eastern Washington and Oregon. Environmental effects resulting from timber harvest, fire management, livestock grazing, mining, and irrigation and other factors over long periods of time have become significant collectively. As shown in this document, cumulative effects include human activities and a wide range of hydrologic, landform, riparian forest, and stream channel interactions that couple together by an intricate series of causes and effects. The Council on Environmental Quality defines cumulative effects as "the impact on the environment which results from incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions" (CEQ Regulation 40 CFR 1508.7). Cumulative effects can be difficult to define both scientifically and practically. For example, potential combined effects induced by upland forestry practices within a watershed may include changes in hydrology, temporary and long-term sediment production, transport and storage, and off-site or downstream effects (Swanson 1986). This paper recommends that cumulative effects in upland forests and adjacent regions, which can result both from management practices and from natural events, need to be better defined in terms of the relations between water and sediment transport regimes and changing stream channel and riparian conditions (Baker 1977, Graf 1983, Hack and Goodlet 1960, Knighton 1987).

We recommend that the evaluation of cumulative effects be coordinated between managers and researchers to improve monitoring of the size and duration of flood events, as well as measuring various cause-and-effect factors. For example, as flood events become more influenced by landslides and road failures, monitoring projects should be able to evaluate sediment delivery in source areas, sediment transport and storage patterns in streams, the stability of streambanks, and riparian vegetation (DeBano and others 1990, Ziemer 1981). Monitoring projects should therefore include an array of methods that assess changing stream and riparian conditions. Important measurements should include estimates of sizes of sediment particles moved in relation to discharge; channel adjustment relations of widths, slopes, and peak-flow increases for different channel types; and riparian species presence under different streambank conditions (Grant 1987, Harvey 1987, MacDonald and others 1991, Simon and Hupp 1987).

Long-term monitoring programs need to be applied by researchers and managers to better define changes in temporal and spatial dimensions and mechanisms involved in natural and human induced disturbances. Any assessment of hydrologic characteristics and the responses of stream channels and riparian habitats should consider the findings and recommendations of Baker and others (1988), Dunne and Leopold (1981), Grant (1987), Miller (1990), and Pfankuch (1975). Important goals should include determining peak flow increases for different stream drainage networks; predicting the relation between different peak flows and movements of channel and bank materials; and assessing the causality of changes in channel structure and stability of stream and riparian habitats.

For forests west of the Cascade Range the evidence is currently contradictory, and no agreed-on approaches for assessing how harvested portions of a drainage basin might affect watershed hydrologic and geomorphic conditions (Harr 1979, Harr 1987, Ziemer 1981). The strong possibility exists that dispersion of timber harvest units affects runoff differently in coastal landscapes from the inland forests of eastern Washington and Oregon. Research on inland forests of Colorado shows timber harvests cause significant increases in peak flow (Troendle and King 1987), but harvest patterns applied west of the Cascades may have little effect on peak flows. The more arid and continental inland forests of eastern Washington and Oregon differ from the rain-dominated forests of the westside (Harr 1979) by having harsher climates as well as different hydrologic regimes, geologic-geomorphic formations, and soils and plant associations (Williams and Lillybridge 1983).

Long-Term Monitoring

Concepts, planning, and design procedures needed in developing cumulative-effect programs for watershed, stream, and riparian ecosystems should focus on long-term monitoring (Wissmar, in press). Long-term monitoring programs should be the key component for bringing together management organizations, researchers, and policy makers to improve the management of natural resources. The keystones of such ecosystem monitoring are long-term data records that provide the basis for analysis of environmental assessment objectives, with predictions of outcomes that can be used to modify and improve future projects.

We recommend that management organizations plan to use monitoring actions and information to facilitate decision processes for conserving and allocating resources for future beneficial uses. Wissmar (in press) presents procedural requirements for developing long-term stream-monitoring programs, including reviews of background and historical information to provide precise definitions of long-term objectives, planning considerations, and monitoring methods. Examples are given of specific procedures that need to be identified during the planning process. These procedures include applying management standards to variable conditions encountered in natural ecosystems and detecting the timing of recovery phases of ecosystem development after a disturbance. The procedures are essential for improving the application of management standards to stream and riparian ecosystems.

Ecosystem restoration—We recommend that long-term monitoring plans should be the central component for applying and evaluating restoration programs for degraded watershed, stream, and riparian ecosystems (Maurizi and Poillon 1992). The first step in restoration should be stating the objective of the monitoring plan: for example, to assess the effectiveness of the ecosystem restoration program. Other, more specific objectives include assessing whether, over time, the restored ecosystem is providing the planned functions and beneficial uses (Hildebrand and others 1987). These objectives can be addressed by using a long-term monitoring program that includes separate monitoring procedures for implementing, evaluating, and validating the planned activities (MacDonald and others 1991).

The next step is to define success criteria for the restoration effort. Criteria for success of projects can be defined by scrutinizing plan objectives and components. Important components needed in developing the restoration plan include background information; long-term objectives; planning considerations, and long-term monitoring procedures. Examples of background data needed to plan the restoration of stream and riparian ecosystems includes historical review of disturbances induced by natural events and human activities; landscape information in terms of topographic scales, bedrock geology, geomorphic landforms, hydrologic regimes, and distribution of stream and riparian habitats (MacDonald and others 1991, Platts and others 1983); stability of streambanks with and without riparian vegetation; and the feasibility of conserving riparian and transitional upland vegetation buffers as filters for surface water and debris movement, and as habitats for wildlife (Gregory and Ashkenas 1990).

The formation of long-term objectives can be the most important component of the restoration process (Wissmar, in press). Long-term objectives can include criteria for success thus providing a basis for assessing ecosystem conditions after restoration (Gore 1985, Maurizi and Poillon 1992, Turner 1987). The long-term objectives can be defined in three ways: as endpoints or points in time; as plan predictions; and as monitoring parameters expressed as standards required for assessing the success of predictions. The key question to be answered when forming these objectives is: What is the desired recovery or developmental stage in the ecosystem that meets your objectives?

To address many of the issues and challenges facing the long-term monitoring of ecosystems and to meet the objectives of restoration plans, we recommend that procedures to detect long-term recovery phases of altered and restored ecosystems should be simple. Most conventional sampling design and statistical methods require various levels of resolution of data and complex analytical approaches that can be difficult to apply to large ecosystem-monitoring programs. Wissmar (in press) discusses a simple procedure for detecting recovery phases in stream ecosystems. In response to land-use disturbances such as logging, stream ecosystems exhibit various stable and degrading phases. Additional research is needed to detect these different phases and to forecast recovery times.

Monitoring parameters and thresholds—Long-term monitoring procedures should give consideration to the scale of the program. Stream and riparian restoration programs have different monitoring requirements than do smaller site-specific projects. Ecosystem-scale programs require monitoring procedures and parameters capable of assessing the influences of natural and human-induced disturbances and land-water interactions that play important roles in causing cumulative effects. These procedures should have parameters with reliable and robust qualities suitable for accurately recording changes in natural conditions of ecosystems and capable of providing variability statements. These parameter qualities are required to improve the application of management standards to dynamic ecosystems.

Management organizations commonly apply standards in terms of desired threshold concepts with undefined limits of acceptability. The use of thresholds is questionable when they do not take into account the natural variability of an ecosystem. A more meaningful procedure is to apply standards that define the limits of acceptable and unacceptable conditions within the spatial and temporal variabilities inherent in dynamic ecosystems (Wissmar, in press). We suggest that a useful and simple definition of the variability of a standard involves the confidence interval (C.I.) of a sample mean. The sample mean and confidence intervals can be obtained through analysis of ecosystem monitoring records. The use of these statistics can bring greater certainty to decision processes.

The definition of the confidence intervals (C.I.) of a sample mean can be demonstrated through analysis of monitoring data for large woody debris in stream channels. In the Pacific Northwest, large woody debris is critical to the structure and function of stream and riparian habitats (Bilby and Ward 1989, Carlson and others 1990). Both the retention and mobility of large woody debris within stream ecosystems can alter flow patterns that create pools and other habitat types by influencing sediment storage and transport, streambank stabilities, and associated fluvial-geomorphic conditions. The recruitment of large wood to stream channels depends on riparian forest-stand characteristics, hillslope gradients and other landform characteristics, and the frequency of natural disturbance events (Wissmar and Swanson 1990).

For large woody debris, an important objective for the analysis of monitoring data can be the development of a standard applicable to stream-channel reaches throughout a watershed (Bilby and Wasserman 1989). This standard can be expressed as the amounts and distributions of different sizes of large woody debris stratified by channel-width categories for upstream and downstream reaches of a stream. The first step is to calculate the sample mean for large woody debris for each of the width categories of a reach. The next step provides the confidence intervals of sample means. At this stage, a decision can be made about

the desired level of significance—for example, 10 percent or $p = 0.1$. This probability level can be used to evaluate whether the mean of a large woody debris population lies between the confidence intervals. If so, only 1 chance in 10 may exist that the large woody debris value and the related decision are mismatched.

We recommend that applying confidence intervals as variability statements to managing ecosystems is most useful when the confidence intervals for the mean of a standard represent natural baseline conditions of unmanaged ecosystems, such as large woody debris in streams in wilderness areas. Confidence intervals for natural variations can be compared to large woody debris values from altered stream ecosystems. Values falling outside the confidence interval can be denoted as exceeding the means expected for natural baseline conditions. Extreme deviations that can be attributed to conditions caused by both natural and unnatural disturbances can also receive attention.

Multiple standards and landscape considerations—The evaluation and validation of standard variability should also consider the possible use of multiple standards for identifying and forecasting ecosystem conditions (Wissmar, in press). But multiple standards, like large woody debris densities, stream substrate compositions, and soil stabilities vary according to their spatial positions in landscapes. Thus, applying these standards must consider the entire landscape, including watershed, stream, and riparian ecosystems. Examples of considerations for stream ecosystems include changes in scale of stream-channel widths and gradients, as well as changes in entrenchment and sinuosity relative to larger spatial features like geomorphic deposits, valley landforms, watershed reliefs, and drainage density.

Multiple standards make possible the assessment of potential degradation in environmental conditions caused by both natural and management-induced disturbances. Potential for degradation can be identified when several standards simultaneously approach or fall outside the confidence intervals for their respective means. If the confidence intervals are exceeded for different standards of a stream, an ecosystem may be very sensitive to disturbances.

The use of different standards to identify sensitive ecosystems should be an asset in future management activities in landscapes with different management histories and from different geologic, hydrologic, and climatic regions. In such circumstances, monitoring records of management practices and changing natural conditions should provide information feedback useful in future planning so as to avoid sensitive areas in ecosystems. Sensitive areas of stream and riparian ecosystems can span several spatial scales in a watershed. The largest sensitive areas might include stream reaches whose geomorphic conditions are susceptible to potential cumulative effects resulting from land-use practices. Smaller landscape units can include stream habitats that are sensitive in terms of an animal's life-history requirements, for example, fish spawning and rearing habitats.

Institutional considerations—The Forest Service as a management organization historically has favored developing long-term monitoring programs for forest, stream, and riparian ecosystems. The Forest Service has the longest history of land-use planning of any government agency. The initial legal basis was laid by the Organic Act of 1897, which gave the Forest Service a wide management window to plan for improving and protecting National Forests for “securing favorable conditions of water flow, and to furnish a continuous supply of timber.” The requirement for continuous supplies of resources implies the need for sustained monitoring activities with the objective of better management and conservation.

The National Forest Management Act of 1976 (NFMA) presents a strong precedent for developing long-term programs for both stream and terrestrial ecosystems. The Act requires comprehensive Forest Plans for each of the 154 National Forests, thereby focusing Forest Service management. The NFMA requires several planning documents. As required by NFMA, most attributes of a Forest Plan can be implemented and improved by developing long-term monitoring programs. With continuous evaluations of objectives and their refinements through iterative amendment processes, this objective can be accomplished.

In the Pacific Northwest, examples of Forest Service implementation plans that attempt to address the needs of stream monitoring programs can be found in *Steps of the Journey: Forest Plan Implementation Strategy* (U.S. Department of Agriculture, Region 6, 1990) and the *Columbia River Basin Anadromous Fish Habitat Management Policy Implementation Guide* (U.S. Department of Agriculture, Regions 1, 4, 6, 1991). A summary of the types of information needed to implement such plans can be found in Meehan (1991). This publication presents a 10-step Forest Service planning procedure for streams in forest and rangeland ecosystems in addition to reviewing other U.S. Federal agency planning processes (Brouha 1991).

Other complementary information includes a review of changes in salmonid habitat over 50 years in eastern Washington and Oregon (McIntosh and others 1993) and the USDA Forest Service PACFISH Strategy (in press). Many of the concepts being incorporated into the PACFISH Strategy were developed in the Upper Grande Ronde River Anadromous Fish Habitat Protection, Restoration, and Monitoring Plan (Anderson 1992). Other groups developing plans for restoring and maintaining salmonid populations in the Columbia River include The University Task Force (1992), The Pacific Rivers Council, Inc. (1993) and related resource projects of the American Fisheries Society and the Wilderness Society, and the timber industry (for example, the Oregon Forest Industry Council). Additional recent sources of river-basin information include the Washington Department of Fisheries ongoing revisions of inventories of salmon and steelhead stocks, Wild and Scenic River management issues (Wissmar and others, in press), and the National Research Council reports on natural-resource restoration and conservation (for example, National Research Council 1990, 1992a, 1992b). Some very useful insights about ecosystem restoration can be obtained by reviewing *How To Restore Our Trout Streams*, by J.S. Van Cleef (1885).

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APPENDIX A

Common Name	Scientific Name
Fish	
Brook trout	<i>Salvelinus fontinalis</i> Mitchell
Bull trout	<i>Salvelinus Confluentus</i>
Chinook	<i>Oncorhynchus tshawytscha</i> Walbaum
Coho	<i>Oncorhynchus kisutch</i> Walbaum
Cutthroat	<i>Oncorhynchus clarkii</i> Richardson
Dace	<i>Rhinichthys</i> sp.
Lamprey	<i>Petromyzonidae</i>
Rainbow	<i>Oncorhynchus mykiss</i>
Sculpin	<i>Cottidae</i>
Steelhead	<i>Oncorhynchus mykiss</i> Richardson
Sucker	<i>Catostomidae</i>
Sunfish	<i>Lepomis</i> sp.
Whitefish	<i>Prosopium Williamsoni</i> Girard
Insect	
Caddisfly	<i>Dicosmoecus gilvipes</i>
Plants	
Aspen	<i>Populus tremuloides</i> Mich ex.
Big mountain sagebrush	<i>Artemisia tridentata vaseyana</i>
Cottonwood	<i>Populus trichocarpa</i> Torr. & Gray
Ponderosa pine	<i>Pinus ponderosa</i> Dougl. ex Laws.
Poplar	<i>Populus</i> spp.
Western juniper	<i>Juniperus occidentalis</i> Hook
Willow	<i>Salix</i> spp.
Wyoming big sagebrush	<i>Artemisia tridentata wyomingensis</i>

Historical and Current Roles of Insects and Pathogens in Eastern Oregon and Washington Forested Landscapes

by

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INTRODUCTION

Every forest ecosystem has its own unique association of native insects and pathogens. When ecosystem attributes, such as plant species composition, tree density, canopy structure, and patchwork pattern change, so do insect and disease complexes. Each landscape development pathway yields a unique insect and pathogen population response. One trajectory may mean prosperity for one suite of insects and relative obscurity for others. Varying only species composition or density or canopy structure has profound effects on pathogen and insect population responses.

Eastside Oregon and Washington landscapes have been dramatically altered by forest management activities of this century. The goal of this paper is to contrast historical and current roles and scales of insect and pathogen disturbances. Highlighted will be the relation of insect and pathogen disturbances to site quality, potential vegetation, and fire regimes. Discussion will also focus on interactions among forest insects and pathogens resulting from changes in scale and intensity of their disturbances, and current size and configuration of their habitats.

Bergoffen (1976) has hypothesized that changes in the eastside forest ecosystems stem largely from two historical management activities—effective fire exclusion, beginning with the creation of the Forest Reserves in 1905, and selective timber harvesting that started with the first European settlers, but was greatly accelerated after World War II (Bolsinger and Berger 1975). Grazing, roading, defoliator suppression, mining, and custodial land management also had significant effects (see papers by Agee, Irwin and others, McIntosh and others, Oliver and others, Wissmar and others 1993). Historically, fire was the most influential disturbance to eastside forest landscapes (see Robbins and Wolf 1993, for an excellent historical review of the settlement of the Intermontane Northwest). Before European settlement, many forests of the interior West were visited by frequent, low-intensity fires that resulted in landscapes tolerant of pathogens, insects, and fires. This fire regime was particularly true for landscapes dominated by ponderosa pine¹ at low and middle elevations. Wickman (1992) revives accounts of early pioneers traveling the Oregon Trail in the Blue Mountains; they described forests of ponderosa pine, with little brush, abundant grasses and herbs, an open parklike appearance, and the look of forests that frequently underburned. Early foresters were also impressed by the parklike stands, dominated as they were by magnificent, old ponderosa pines and maintained by fire (Langille and others 1903, Lieberg 1899, Munger 1917).

Insects and diseases were part of these simplified forests, but as Wickman (1992) pointed out, the extent of their influence was typically smaller, disturbance events of shorter duration, and the severity of effects less than we observe today. In fact, because of their contribution to animal and plant habitat development, biomass and nutrient recycling, and patch and landscape diversity, historical effects of insects and pathogens should be perceived as beneficial and integral to fire-adapted ecosystems.

Upper elevation forests of the premanagement-era burned less often and more intensely. Patches regenerated by fires covered large areas. Often, entire landscapes were regenerated by the largest fires. Seral species initially invaded burned landscapes, followed by more shade-tolerant species with increasing passage of time. Landscapes that burned every 100 years or more were comprised of a patchwork of stands with mature and overmature seral overstories of western larch, Douglas-fir, lodgepole pine, and occasionally ponderosa pine, with understories of shade-tolerant species of various sizes and ages, depending on more recent fire history. Most of the insect and disease activity we observe today occurred historically within these high-elevation areas. The effect of fire exclusion on the health of high-elevation ecosystems is relatively minor compared with effects on low- and mid-elevation ecosystems; however, high-elevation ecosystems are now highly interconnected with mid-elevation ecosystems that have been substantially modified by fire exclusion and selective harvesting. Insect and pathogen disturbances, once limited by vegetation conditions dictated by fire frequency and intensity, now freely extend to larger areas.

¹Scientific names for all taxa mentioned are given in appendix A.

Many current eastside landscapes, with fire return intervals now prescribed by management rather than by fuels and environment, are dominated by shade-tolerant tree species, with little of the patchiness and clumpiness that characterized historical landscapes. In addition, tree and shrub densities are substantially increased. Trees, shrubs, grasses, and herbs compete for often severely limited water, sunlight, and nutrients. Increased competition for limited site resources, coupled with dramatically increased abundance of shade-tolerant species, has invited large increases in pathogen and insect populations. The extended drought of the last 7 years has accentuated these escalating effects.

With the exception of a few insects and pathogens introduced to this continent in the last century—notably the larch casebearer (Tunnock and Ryan 1985), the balsam woolly adelgid (Mitchell 1966), and white pine blister rust (Hagle and McDonald 1989), the forests east of the Cascades have the same insect and disease associates now that they had 100 years ago. The difference between then and now is the scale of interaction between insects, pathogens, and their hosts, in both space and time. Although large insect outbreaks clearly occurred before the European settlement of the West (Lieberg 1899, Swetnam and Lynch 1989, Wickman and others 1993), the landscape patterns of vegetation ensured that most disturbances were brief and spatially confined. Some insects now appear to operate nearly continuously over entire landscapes.

A staggering array of insects and fungi is found in interior forests of Oregon and Washington. Some species have evolved relations of mutual benefit to themselves and their hosts. Others are opportunistic on injured or stressed trees, shrubs, or herbs. Most act in beneficial processes such as pollination, or water and mineral nutrient imbibition by plants, nutrient cycling, soil development and moisture retention, reduction of large plant residues and detritus, or biological control of other organisms. All species play an important role in ecosystem processes; a relatively few species can capitalize on changes in vegetation conditions over large areas. These latter few are the focus of this paper:

- ☐ Western spruce budworm
- ☐ Douglas-fir tussock moth
- ☐ Pine bark beetles—the western pine beetle, the mountain pine beetle, and the pine engraver
- ☐ Douglas-fir beetle
- ☐ Fir engraver
- ☐ Spruce beetle
- ☐ Laminated root rot
- ☐ Armillaria root disease
- ☐ P- and S-group annosum root diseases
- ☐ Dwarf mistletoes of true firs, Douglas-fir, western larch, ponderosa pine, and lodgepole pine
- ☐ Indian paint fungus
- ☐ White pine blister rust, Comandra rust, and stalactiform rust
- ☐ Brown cubical butt rot

Mountainous regions of eastern Oregon and Washington are dominated by coniferous forest cover. Forested provinces of the east side have been classified according to climatic (and occasionally edaphic) climax plant associations (Daubenmire and Daubenmire 1968, Johnson and Clausnitzer 1992, Johnson and Simon 1987, Volland 1985, Williams and Lillybridge 1983, Williams and Smith 1991, Williams and others 1990). Taxonomically related plant associations are aggregated into series named after the dominant climax conifer. In this paper, we have arranged our discussion of changing roles of insects and pathogens from historical to current conditions by forested climax series. We begin with high-elevation series and finish with low-elevation series and a discussion of the unique pathology and entomology of the lodgepole pine series of the pumice plateau of central Oregon.

All forests have been altered to some degree by the last century of resource management and fire protection, but the greatest changes in vegetation, and insect and pathogen response, have occurred in low- and middle-elevation grand fir, Douglas-fir, and ponderosa pine climax forests. Because these forests have been influenced most by fire protection and selective timber harvesting, they receive emphasis in our paper.

SUBALPINE FIR AND MOUNTAIN HEMLOCK SERIES

Climax subalpine fir forests are found at the higher elevations in all major ecoregions of eastern Oregon and Washington (Franklin and Dyrness 1973, Omernik and Gallant 1986). They are the primary subalpine forests of the eastern Cascade Range. Most stands are above 4800 feet, but subalpine fir can easily extend farther downslope to 3000 feet in cool valleys, and along avalanche tracks (Franklin and Mitchell 1967). Fires are infrequent in these cool, moist environments. Before the era of fire protection, fire return intervals for subalpine fir in the Washington Cascade Range were typically more than 100 years, often more than 200 years. Drier subalpine forests to the east had somewhat shorter fire intervals, but usually longer than 150 years. Fires in this series, though infrequent, were very intense and usually resulted in complete stand replacement on 70 to 100 percent of the affected area (Agee 1990).

The mountain hemlock series is a minor subalpine series only occurring in scattered locations near the Cascade Crest, and in two populations in the Eagle Cap Wilderness of the Blue Mountains of northeast Oregon (Agee 1993). Little is known of the fire ecology of mountain hemlock forests. What is known suggests that fire intensities and return intervals are similar to those of subalpine fir forests.

Historical Forests

Western spruce budworm—The western spruce budworm infrequently visited subalpine fir forests, and probably was not a major factor in mountain hemlock forests. Unless otherwise indicated, most discussion here will center on subalpine fir forests. Defoliation, when it occurred, was rarely damaging. Of the subalpine fir climax sites exposed to budworm defoliation, those occurring at the lowest elevations were most frequently and severely defoliated. In these locations, subalpine fir stands were often adjacent to grand fir, Douglas-fir, and white fir climax sites; some that were regularly underburned and dominated by seral species; others burned less often, creating an uneven patchwork of early-, mid-, and late-seral stands. Fingers of subalpine fir extended into this patchwork, and mixed coniferous stands with grand fir, white fir, or Douglas-fir overstory and understory components adjoined subalpine fir stands.

Continuity of budworm-susceptible stands was greater in this mid-elevation region where fire regimes were historically of moderate rather than high severity. Budworm outbreaks in the lower extremities of the subalpine fir series were probably of short duration and small in extent relative to current-day outbreaks, minimizing defoliation damage to subalpine fir. Today, areas most susceptible to budworm defoliation are the driest sites of the Douglas-fir, grand fir, and white fir series. Historically, many of these sites were frequently underburned at low intensity, maintaining predominantly seral vegetation. Better sites of these series were less susceptible and less frequently defoliated. Perhaps extended droughts predisposed these more mesic and drier sites to defoliation. We surmise that the extent, duration, and severity of

defoliation in subalpine fir varied with the amount of defoliation of Douglas-fir, grand fir, and white fir in adjacent stands. Initiation of outbreaks in subalpine fir was unlikely. Outbreaks more likely developed in adjacent Douglas-fir, grand fir, or white fir stands during droughty periods and extended into subalpine fir where environmental conditions for budworm were typically suboptimal, and budworm populations declined.

The western spruce budworm also fed on associated Engelmann spruce. Defoliation of spruce was rarely significant, but subalpine fir, which is quite susceptible and sensitive to budworm feeding particularly in the Cascades of northern Washington (personal observations, R. Mitchell), suffered some growth loss and topkilling, and occasionally tree mortality. As a result, budworm defoliation might have killed single subalpine fir trees or trees in small groups, but it is unlikely that mortality was widespread. The effect of localized group killing would have created patches of snags that could be used by birds and carpenter ants, agents whose predation tends to keep budworm populations low under natural fire disturbance regimes (Campbell and others 1983). Defoliation also enhanced mineral cycling from caterpillar frass (larval excrement) (Crossley 1970, 1977; Klock and Wickman 1978) and added diversity to otherwise even-textured landscapes.

Douglas-fir tussock moth—In eastern Oregon and Washington, Douglas-fir tussock moth populations feed readily on subalpine fir and damage is occasionally significant in modern times, but defoliation seldom results in long-term growth or mortality effects. Whether tussock moth was a significant problem in presettlement times is somewhat problematical because host stands before fire control were not so extensive as now. Although the tussock moth can be destructive, it prefers warm, dry sites of the Douglas-fir, grand fir, and white fir series (Stoszek and Mika 1978, Wellner 1978, Wickman and others 1973).

Mountain pine beetle—Lodgepole pine, an important seral species in both subalpine fir and mountain hemlock series, often regenerated in nearly pure stands after stand-replacement fires, if it was present in the former stand. Stand-replacement fires at intervals less than 200 years favored development of lodgepole pine. In subalpine fir forests, fire severity was sometimes great enough to completely eliminate any residue of subalpine fir because entire trees were consumed (Clinton Williams, personal communication). Fire-regenerated lodgepole pine stands were usually overstocked and stressed by excessive intertree competition from an early age. Suppression mortality and snow-breakage rarely reduced stocking sufficiently to relieve stress. After six or seven decades, some stems in these stands would reach a sufficient diameter to support a mountain pine beetle brood. Mountain pine beetle mortality would continue for decades, eliminating the largest stems and trees in small groups by successful mass attack.

Large, synchronous outbreaks seldom developed at the higher elevations typical for these series, presumably because of shorter growing seasons, and poor larval and young adult overwintering. After longer intervals without fire (> 200 years), these stands would eventually break up and be dominated by subalpine fir and other associated shade-tolerant species. Outbreaks have been recorded in high-elevation stands that included whitebark pine (Burke 1990).

Spruce beetle, fir engraver, western balsam bark beetle—The spruce beetle was likely a regular but minor tree killer of Engelmann spruce in the subalpine fir series, and judging from its current pattern (Scott 1991), usually attacked overmature, windthrown trees. Butt rot associated with S-group annosum root disease and tomentosus root disease is extensive in maturing spruce stands. Overmature spruce trees with butt rot collapse under high winds. Spruce beetle populations were presumably maintained in windthrow of mature and overmature spruce, and in fire-killed spruce. Other bark beetles providing background mortality in conifer associates of Engelmann spruce were the silver fir beetle, and the fir root beetle. Both are associated with windthrown and diseased Pacific silver fir (Thomas and Wright 1961). In the same stands, the fir engraver and western balsam bark beetle would have also been minor tree killers of subalpine fir, and grand or white fir, although (as now) drought periods would have made mortality more visible.

Annosum root disease—Annosum root disease (S-group) was prevalent in a wide variety of plant communities of the subalpine fir and mountain hemlock series, infecting subalpine fir, grand and white fir, Engelmann spruce, Pacific silver fir, western hemlock, and mountain hemlock. Annosum root disease attacked trees of all ages, causing root and butt rot at maturity and occasionally killing low-vigor trees in overstocked stands. Grand fir and white fir were often killed by this root disease.

Brown cubical butt rot—Another root and butt disease common to the subalpine fir series was brown cubical butt rot; western larch, lodgepole pine, and Douglas-fir were the primary hosts. Intertree transmission of this root disease in infection centers was root to root by growth of infective mycelia through litter. New infection centers were initiated when spores of the pathogen infected recent fire scars of mature Douglas-fir and western larch. Butt defect associated with this disease was responsible for the collapse of many of the oldest (200 years and older) seral overstory trees.

Tomentosus root disease, Indian paint fungus—Tomentosus root disease was common in maturing lodgepole pine stands, especially in the northern Rocky Mountain ecoregion, where it caused tree collapse and windthrow. The Indian paint fungus was also prevalent in both the subalpine fir and mountain hemlock series causing heart rot of true firs, western hemlock, and mountain hemlock. Hosts were infected as suppressed saplings and small poles. Infected understory trees were released with the break-up of the seral overstory. Infections were activated when trees were wounded near the original point of infection. Activated infections in true firs and hemlocks resulted in substantial heartwood defect, an important habitat for primary cavity-excavating bird species and secondary cavity users.

Laminated root rot—Laminated root rot was found in all coniferous species of both the mountain hemlock and the subalpine fir series, but was especially prevalent and visible where Douglas-fir, grand (white) fir, or mountain hemlock (highly susceptible hosts) were present in abundance. Douglas-fir was a common seral species in the subalpine fir series, regenerating with western larch, lodgepole pine, and western white pine after stand replacement fires or other major disturbances. Environments favorable to spread of this root disease were those dominated by susceptible hosts; western larch, western white pine, and lodgepole pine discouraged spread of this disease.

Armillaria root disease—Armillaria root disease infected and killed Douglas-fir, which was seral in both series. Because the fungus that causes Armillaria root disease is both an aggressive pathogen and an opportunist, vigorous as well as injured trees, and those stressed by other insects or diseases, overstocking, or drought also succumbed to this root disease. Stressed or injured trees of coniferous species ordinarily tolerant or resistant to infection were often killed by this fungus. In late-successional plant communities of the subalpine fir series, laminated root rot apparently decreased, although only visibility expressed as mortality changed with the declining dominance of Douglas-fir. Laminated root rot continued to spread to other, less-susceptible hosts, causing butt defect. S-group annosum root disease and tomentosus root disease expressed as butt defect increased with increasing abundance of late-successional species.

None of the native insects or diseases were individually significant mortality factors in the historical subalpine fir series. Collectively, they responded to developing instabilities within ecosystems, reduced competition for limited site resources, and between fires, generated most of the woody debris important to subalpine fir ecosystems. That woody debris was doubtless important to a succession of fragmenters and decomposers, and it was essential to the infrequent fires that regenerated these forests. Within the mountain hemlock series, laminated root rot was a significant mortality factor influencing successional status, fire intensity, and fire behavior.

Current Forests

The principal effect of fire suppression in subalpine forests is the marked reduction in the number and size of stand-replacement fires. Conflagrations in any one area were infrequent in historical times, but when they did occur, they were large-scale landscape events. Burned areas naturally regenerated over decades, creating large, unfragmented patches with the qualities of deep interior forest. The most common disturbances today are small harvest units that reproduce none of the characteristics of large-scale disturbances. Fires still commonly occur but they are easily suppressed. Accordingly, early- and mid-seral landscapes have been gradually lost (see Lehmkuhl and others 1993).

Western spruce budworm—Defoliators like the western spruce budworm that prefer feeding on Douglas-fir and true fir needles have not dramatically expanded their influence in the subalpine fir series in this century. That may be changing, though. Current outbreaks of the budworm in the Cascades of central Oregon and the Blue Mountains of northeast Oregon suggest that severe outbreaks of long duration can occur in these forests. This pattern is difficult to explain, but it could stem from a gradually expanding food base. Because subalpine fir and balsam fir are genetically very similar, experiences in eastern Canada could offer an explanation. Holling (1986) reported that birds kept budworm populations in check in balsam fir in Canada when stands were young. As the balsam fir forests matured, the supply of new needles gradually expanded and so did budworm populations. Outbreaks developed when the number of budworms became so large that the existing bird populations could not keep pace with budworm population growth. A relation such as this, exacerbated by the current persistent drought, could contribute to the severe outbreaks in central and northeastern Oregon.

Current subalpine forests are more successional advanced and contain many more true fir stems than did historical forests. As in historical forests, the extent, duration, and severity of defoliation in modern-day subalpine fir forests correspond with defoliation of adjoining Douglas-fir and grand (white) fir forests. If patches of Douglas-fir and grand fir forest are scattered and embedded in a seral-dominated forest matrix, budworm episodes will be short and mostly undamaging. If these areas are large and contiguous, budworm outbreaks can be long and damaging, with increasing tree mortality and topkilling. Adjacent subalpine fir stands will be affected accordingly.

Mountain pine beetle, western balsam bark beetle, spruce beetle, fir engraver—Large-scale mountain pine beetle infestations in lodgepole pine will be more infrequent with continued fire control. Lacking stand-replacement fires to regenerate new stands, lodgepole pine abundance is decreasing throughout the east side. Continued thinning from above by the mountain pine beetle, coupled with the establishment of shade-tolerant understories, is gradually reducing the abundance of lodgepole stands in the high elevations. Mountain pine beetle attacks on western white pine have increased dramatically with the introduction, early in this century, of white pine blister rust. White pine trees, and the tree tops declining from stem-girdling infections of the rust, are destroyed by the mountain pine beetle. Western balsam bark beetle and spruce beetle associated with old, diseased subalpine fir and spruce will likely increase because both old trees and disease incidence are increasing. Fir engraver mortality and topkilling will increase because host type has increased, and because heavy stocking reduces tree vigor and capacity to resist attacks. Drought will accentuate fir engraver effects.

Larch casebearer, balsam woolly adelgid—The larch casebearer and the balsam woolly adelgid are two destructive insects introduced into the region in the last decade (Denton 1979, Mitchell 1966). Initial parasite introductions apparently subdued casebearer populations (Ryan 1990), but casebearer damage is again visible in many areas of the central Oregon Cascades and in northeastern Washington in the last two years (Hessburg and Flanagan 1992a, 1992b). The balsam woolly adelgid can be severely damaging to true firs in western Oregon and Washington despite the introduction of natural enemies (Mitchell and Wright 1967). Subalpine fir is especially sensitive to attack and is often killed where the host is invading meadows

and lava beds (Franklin and Mitchell 1967, Mitchell 1966). East of the Cascades, the woolly adelgid has been found in only a few environments where subalpine fir has crept downslope into what would normally be considered grand fir climax sites (personal observations, R. Mitchell). Unless distribution and damage change unpredictably, the woolly adelgid cannot be considered a serious threat to eastside subalpine fir forests. The few trees that are killed in high-elevation stands function as upright snags for a long time (personal observations, R. Mitchell) and are probably beneficial to wildlife.

Laminated root rot, Armillaria root disease, annosum root disease—The increasing period between fires as a result of fire exclusion, and the gradual decline in the abundance of Douglas-fir have produced an apparent decrease in laminated root rot expressed as mortality. A lack of fire has reduced the visible manifestation of this disease but it has not eliminated the fungus. The disease continues to spread in less-susceptible hosts, causing a butt defect of maturing trees. Armillaria root disease and S-group annosum root disease are increasing in subalpine fir and other true firs because firs are older and more abundant (Filip, in press). More root disease also means more bark beetle mortality from the western balsam bark beetle and the fir engraver.

Laminated root rot centers in mountain hemlock may affect the initiation and spread of fire by killing large numbers of trees of various sizes (Dickman and Cook 1989). Dead trees, both standing and down, in turn increase the frequency of wildfires. Increased frequency of crown fires decreases the incidence of visible laminated root rot by converting the forest from hemlock to root disease-resistant lodgepole pine. In these areas, fire has reduced the visible infestation but has not eliminated the fungus. The disease continues to spread in less susceptible hosts, acting as a butt defect of some mature trees.

WESTERN HEMLOCK AND WESTERN REDCEDAR SERIES

The western hemlock and western redcedar series are found east of the Cascade crest in Washington and in northern Oregon (Franklin and Dyrness 1973, Johnson and Clausnitzer 1992, Johnson and Simon 1987, Volland 1985). Both are well represented in northeastern Washington in the Pend Oreille River basin and elsewhere in the northern Rocky Mountain ecoregion, which has a maritime climate influence. Coniferous tree species found within these series are those common to the grand fir and subalpine fir series, and the mountain hemlock series. Douglas-fir, grand fir, western larch, western white pine, and lodgepole pine are the most abundant seral species.

For eastside conditions, these forests receive relatively high rainfall, and fire return intervals are often more than 100 years. When fires occurred, they were variable in intensity, resulting in either complete stand replacement, a partially killed overstory, or underburning with little overstory mortality (Williams and Smith 1991, Williams and others 1990). For the western hemlock series, severe fires at intervals less than 200 years tended to favor lodgepole pine regeneration when lodgepole pine was in the original stand. Stand-replacing fires at intervals longer than 200 years tended to favor western larch and western white pine. Fires of moderate intensity favored Douglas-fir, larch, and white pine (Williams and Smith 1991). Before the turn of the century, western white pine was abundant in the western hemlock and western redcedar zones, especially in northeastern Washington, a significant contrast with the rest of eastern Oregon and Washington, where presence of western white pine is incidental.

Historical Forests

Mountain pine beetle, western spruce budworm, Douglas-fir beetle, fir engraver—Few insect outbreaks have been recorded in either series. Tree killing by the mountain pine beetle was common in mature, overstocked lodgepole pine, especially in trees with diameters large enough to support broods. Large outbreaks that destroyed entire stands were unlikely. Ordinarily, small groups of overstory trees were mass-attacked and killed. The result was a gradual thinning from above and a steady accumulation of

snags and flammable fuels. Western spruce budworm populations likely fluctuated in number and size, but serious defoliation in either forest type is doubtful. Analysis of climatic patterns by Kemp and others (1985) indicated that hemlock and redcedar climax forests resided in low and moderate outbreak-frequency areas. The Douglas-fir beetle and fir engraver responded to root-disease-weakened Douglas-fir and true firs, contributing to their demise. Outbreaks of either beetle must have been exceptional and were associated with large-scale fires or windthrow. On balance, we can deduce that insect disturbances were mostly beneficial, providing habitat, variety, and stability to ecosystems under historical fire disturbance regimes.

Laminated root rot—Diseases probably played a greater role in succession and fire history than did insects, though their effects are somewhat inseparable. The root-disease ecology of western hemlock and western redcedar climax forests on the eastern slope of the Cascades was very similar to that in western hemlock climax forests of the western slope of the Cascades today. Four root diseases were a primary influence in these forests: laminated root rot, *Armillaria* root disease, S-group annosum root disease, and brown cubical butt rot. Laminated root rot was especially common in early- and mid-seral stands dominated by Douglas-fir and grand fir, where trees of all ages were killed. Douglas-fir and grand fir, infected when mature or overmature, often developed extensive butt defect before succumbing to root disease. As more shade-tolerant conifers seeded in or released with the gradual break-up of the overstory, they were also infected but with little effect until they reached maturity. Once trees were mature (> 150 years old), butt rot would develop in western hemlock, Pacific silver fir, subalpine fir, noble fir, Shasta red fir, and occasionally western larch and western white pine. Mountain hemlock, when present, was killed by this root disease. As with Douglas-fir and grand fir, mountain hemlock infected when mature or overmature would often develop extensive butt defect before dying.

Armillaria root disease—The role of *Armillaria* root disease in western hemlock and redcedar climax forests of the eastern slope of the Cascades was unique, considering its role elsewhere on the east side. Douglas-fir in most drier series was highly susceptible to *Armillaria ostoyae* at all ages (Hadfield and others 1986). Within these series on the eastern slope, juvenile (< 40 years old) Douglas-fir was most susceptible; mortality of older, robust trees and stands was relatively uncommon. *Armillaria* root disease also caused rapid juvenile mortality in almost every other coniferous species in these two series, with the exception of western redcedar. Fire-regenerated landscapes would experience mortality as a thinning effect until stands were dominated by pole-sized trees. Subsequently, *Armillaria* root disease was a mortality agent of low-vigor trees of developing stands.

In the northern Rocky Mountain ecoregion (Colville National Forest), localized mortality attributable to *Armillaria* root disease in young and old western redcedar has been observed (personal observation, P. Hessburg). In hemlock and redcedar climax forests of this same ecoregion, Douglas-fir is susceptible and can be killed at any age. Stressed and damaged conifers of all species are also host to this root disease.

Annosum root disease—S-group annosum root disease primarily caused butt defect in western and mountain hemlock, Pacific silver fir, and subalpine fir, although grand fir was killed when infected. Incidence in some mature, late-successional stands would have exceeded 50 percent if current-day stands are any indication. On the west side of the Cascades, Goheen and others (1980) found that, although rates of infection may be high in young hemlock, defect is incidental in wounded or unwounded trees until infected trees reach maturity. We presume that a similar relation exists for infected western hemlock and Pacific silver fir in eastside hemlock and redcedar series forests.

Brown cubical butt—Brown cubical butt rot spreads from host to host much like any root disease, but its influence on succession and fire history is more subtle and has often gone unnoticed. We surmise that a far greater proportion of eastside stands of all climax series are influenced by this root disease than by any other. Because this disease has no visible manifestation in the form of dead trees, it is overlooked, but it is likely the primary source of butt defect in western larch, Douglas-fir, ponderosa pine, and lodgepole pine on the east side. In historical hemlock and redcedar climax forests, Douglas-fir, western larch, and lodgepole pine were the primary hosts, although all other conifers within the series were occasionally infected.

In eastern Oregon and Washington, tree mortality was exceptional; extensive butt rotting was the norm. Intertree spread occurred primarily via mycelial extension through duff and litter between host roots in close proximity.

Brown cubical butt rot was especially common in western larch and Douglas-fir, and extensive butt rot was evident in trees 200 years old and older. Fire-scarred survivors of former stands were vulnerable because they had new infection sites for decay pathogens, and were often well advanced in age at the time of fire injury. After fires, scars on surviving trees were infected by spores, thereby initiating new centers of disease. In hemlock and redcedar climax forests, Douglas-fir and western larch collapsed in characteristic barber-chair fashion when defect in the butt compromised vertical stability. Brown cubical butt rot has also been isolated from decayed stems in association with woodpecker cavities in northeastern Oregon (Parks and others 1990).

Dwarf mistletoes—Dwarf mistletoes were not particularly damaging or common to hemlock or redcedar climax forests of the eastern Cascades, although western hemlock dwarf mistletoe does extend to eastside western hemlock stands, and can be locally damaging (personal observation, P. Hessburg). Dwarf mistletoes of western larch and lodgepole pine are occasionally associated with stands in these series. We presume their historical association was occasional as well. In western hemlock and western redcedar climax forests of northeastern Washington, dwarf mistletoes played a much greater historical role. Mistletoes of western larch, lodgepole pine, and Douglas-fir were especially damaging when fire return intervals were long. Mistletoe-infected trees surviving prior fires would transmit disease to host conifers in the understory via ballistically discharged seeds. With increasing passage of time between fires, stands would become more layered, more trees would be infected, mistletoe-infected branches would be more severely broomed, and topkilling and tree mortality effects would increase.

Indian paint fungus—In hemlock and redcedar climax forests throughout the east side, the Indian paint fungus was the most widespread stem decay pathogen of living western and mountain hemlock, and grand, noble, subalpine, and Pacific silver fir. Suppressed seedling, sapling, and small pole-timber-sized host trees were infected by spores through vascular traces on small, dead, lateral branchlets. Once released from suppression through break-up of the overstory, quiescent infections were later encased in stemwood as trees increased in girth. Wounds, frost cracks, wind shake, and other injuries near the site of original infection stimulated active decay of the heartwood by the pathogen.

Current Forests

Eastside western hemlock and western redcedar climax forests have been logged considerably since World War II. Because of maritime influence, these forests are highly productive. Many regeneration cuts have been made, but 40-acre clearcuts are currently the largest patches allowed on public lands. This size contrasts with the openings caused by historical fires that once created small, medium, and very large openings in the forest, some measuring thousands of acres. Another important difference centers on the disposition of woody debris: historical fires left dead trees of all sizes on each acre. Dead trees functioned as snag habitat for birds and small mammals for many decades. They eventually collapsed, slowly decayed, and were incorporated into the soil in subsequent centuries. Woody residues influenced soil moisture, texture, and fertility, and created an essential environment for microbes, fragmenting arthropods, and detritus feeders. Current management practices produce a scaled-down version of disturbance and woody residue recycling, and the role of large woody residues is diminished or has been eliminated. Managed hemlock and redcedar climax forest landscapes are also more fragmented and have more edge (Lehmkuhl and others 1993).

Insect and disease disturbances in current hemlock and redcedar climax forests are very much the same as those of a century ago, with a few major differences in successional status or corresponding insect or pathogen responses. The principal difference between historical and current conditions is the scale of landscape disturbances. Reduced scale of fire disturbances has reduced the scale of pathogen and insect

responses to changing successional conditions, but the responses themselves are the same. Perhaps the greatest change in the role of forest diseases in these ecosystems is associated with the white pine blister rust. Introduced to western North America around 1910, the blister rust is now widespread in five-needle pines throughout the United States, and it has taken a significant toll on western white pine in both western hemlock and western redcedar climax forests. Interacting mountain pine beetle populations have responded to the increase in blister rust, and most stem-cankered trees are ultimately killed by the mountain pine beetle. Once a widely distributed seral species in these series, western white pine is diminished in abundance to such an extent that it occurs in some locations now as an incidental species. Rust-resistant white pine have been identified and resistance factors characterized. In the last decade, genetically improved, rust-resistant white pine stocks have been introduced in single- and some multi-line arrangements.

DOUGLAS-FIR AND GRAND (WHITE) FIR SERIES

The grand fir series is the most extensive midslope forest east of the Cascade crest. It ranges in elevation from 1800 to 5100 feet in the eastern Washington Cascades, 2500 to 6500 feet in the Ochoco and Blue Mountains, 3000 to 6100 feet in the eastern Oregon Cascades, and 2200 to 4900 feet east of the Kettle Mountains in northeastern Washington. The Douglas-fir series is less extensive, occurring in lower slope positions than grand fir at elevations ranging from 2100 to 5900 feet in the Blue and Ochoco Mountains, 1400 to 5400 feet in the eastern Cascades of Washington, 2200 to 5400 feet in the Okanogan Highlands of northeastern Washington, and 1900 to 6000 feet on the Colville National Forest. Douglas-fir climax forests in the Blue Mountains are fragmented, often confined to dry ridgetops and south- and east-facing slopes.

The most common seral tree species in both series is ponderosa pine, particularly at low and middle elevations. Ponderosa pine is replaced by western larch at higher elevations and on north aspects. Ponderosa pine achieves its optimum growth in the grand fir series (Daubenmire 1961). Other seral species are lodgepole pine and western white pine. Characteristic of both series—almost as distinctive as the overstory stands of ponderosa pine—are scattered large, open, grassy areas on thin soils.

Under historical fire regimes, many grand fir and Douglas-fir climax forest sites were dominated by seral species that arose from infrequent stand-replacement fires and were maintained by frequent underburning. The most commonly regenerated tree species was ponderosa pine, but lodgepole pine was an aggressive pioneer; because of its serotinous cones and tendency to mature sexually at an early age, it often dominated sites when it was present in the burned stand. Western larch was often the dominant seral species in areas interpreted as having historically moderate- or high-severity fire regimes that were characteristic of north slope environments and higher elevations (Agee 1990, Williams and Smith 1991). Underburning fire regimes had little effect on fire-resistant overstory trees like ponderosa pine and western larch, and open, parklike stands were maintained for centuries. Between fires, shade-tolerant species regenerated in the understory but, because of their thin bark and low crowns, few survived the frequent fires.

Douglas-fir and grand fir climax forests were characterized by low- and moderate-severity fire regimes (Agee 1993). Low-severity fires (< 20 percent of trees killed) maintained parklike stands of seral species. Fires of moderate severity produced a variable landscape patchwork. We would expect that Douglas-fir and grand fir climax forest landscapes were the most diverse of all eastside landscapes under the historical influence of fire. Landscapes created and maintained by moderate-severity fire were constantly changing. Within single-fire events, areas burned by high-intensity fire (20 to 70 percent of the area) were homogenized for a time until unique site characteristics and site potential were manifested, and patches would emerge within patches. Similarly, underburned areas would be homogenized for a time, but each successive underburning event would affect different areas of the landscape, and differences according to species composition, canopy layering, and density would emerge. Excluding fire from Douglas-fir and grand fir climax forests has perhaps been the single greatest blow to landscape diversity on the eastside.

Historical Forests

Late successional and climax plant communities of the Douglas-fir and grand fir series were relatively scarce before the advent of fire control on public lands. Landscapes that were frequently visited by fire were dominated by seral species. Areas that were routinely missed by fire ("refugia") were those that normally burned with difficulty except under extreme weather circumstances: riparian areas, moist sites, high-elevation sites, headwall sites, sites adjacent to rock outcroppings and scree slopes, and north slopes (Cooper and Pfister 1984). This pattern was true of all ecoregions of the east side except for the area of the Colville National Forest that lies in the northern Rocky Mountains ecoregion (Omernik and Gallant 1986), where moderate- and high-severity fire regimes were more typical. Refugia were embedded in seral-dominated landscapes, or they were large areas that burned infrequently and had high-severity fire regimes. With the advent of fire suppression, Douglas-fir and grand fir expanded outward from refugia encroaching on new areas, establishing in the shade of seral overstories (Cooper and Pfister 1984). Historical refugia can be located by identifying the oldest patches of Douglas-fir or grand fir, or by dating old stumps if trees have been harvested.

Western pine beetle—The western pine beetle would have been one of the most obvious insects associated with regularly burned, presettlement Douglas-fir and grand fir climax forests (Miller and Keen 1960). As documented in pioneer journals and old photographs (Burke 1990; Gruell 1983; Gruell and others 1982; Wickman 1987, 1992), low- and mid-elevation forests were dominated by large, old ponderosa pine; the kind of trees preferred by the western pine beetle (Keen 1943, Miller and Keen 1960, Wickman and Eaton 1962). These trees could magnify beetle populations, particularly when stressed by drought. Many trees were killed by western pine beetle during the great drought of the 1920s and 1930s (Miller and Keen 1960). Most years, the role of the western pine beetle was more benign; beetles killed trees struck by lightning, infected with root diseases, and those too old to resist beetle attack.

Beetle-killed pine became snags that provided roosting and nesting habitat for birds, and when snags eventually fell, they provided habitats for various forest vertebrates, decomposers, and invertebrate fragmenters. Beetle-killed pine was a ready source of large and small insect larvae for birds and other insectivores. Woodpeckers snatched late-instar western pine beetles from the outer bark. Shortly after trees died, ambrosia beetles (Coleoptera/Scolytidae and Platypodidae) bored deep into the stem and produced their young. Following the western pine beetle and ambrosia beetles, roundheaded (Coleoptera/Cerambycidae) and flatheaded woodborers (Coleoptera/Buprestidae) mined and channeled stems as saprot claimed the sapwood. Woodborer larval galleries were large, creating ready access for wood decay fungi to the stem interior. In subsequent decades, carpenter ants (Hymenoptera/Formicidae) and termites (Isoptera/Hodotermitidae, Kalotermitidae, and Rhinotermitidae) infested decaying snags and contributed to their ultimate collapse.

Mountain pine beetle—The mountain pine beetle was an important insect of lodgepole pine stands of the Douglas-fir and grand fir series. Some of the first recorded outbreaks were in lodgepole and ponderosa pine (Langille 1903, Lieberg 1899), and the first forest insect control project was funded by Congress in 1910 to suppress an outbreak of the mountain pine beetle in lodgepole and ponderosa pine near Baker, Oregon (Burke 1990). Other early outbreaks have been documented by studying trees strip-attacked by the mountain pine beetle (Mitchell and others 1983a).

Many of the historical outbreaks were obviously severe (Wickman 1990), but the extent and duration of outbreaks were less than we observe today (Mitchell 1988), partly because of greater age diversity that fires created in lodgepole pine forests, the fact that fires would sometimes burn beetle-infested stands, and beetle populations would cycle with developmental stages of stands (Amman 1991, Martin and Mitchell 1980, Mitchell and Martin 1980).

Until regenerated by fire, lodgepole pine stands of the Douglas-fir and grand fir series showed considerable variation in age and structure, reflecting their outbreak and recovery history. In an outbreak, the largest dominant and codominant pine were killed, leaving the lower crown classes to survive. Within a few years, surviving trees responded to improved growing conditions and began expanding their crowns (Mitchell 1987). After 30 or 40 years, tree crowns merged and trees began showing signs of intertree competition. Outbreaks recurred when trees with diameters larger than 9 inches were abundant, and overstocking depressed tree vigor to the point that effective resistance to attack was lost.

Before the 20th century, fires occurred somewhat randomly, ensuring that at any given time, only a small proportion of lodgepole pine stands would be of susceptible size and age. This effect of random distribution of fire regulated both the beetle food supply, and the number of beetles available to attack susceptible trees. The total number of trees killed in a stand depended on stocking within a stand, and beetle populations available to a susceptible stand (Mitchell 1988). Tree vigor also played an important role in susceptibility to beetle attack (Mitchell and others 1983b; Waring and Pitman 1980, 1985), but unmanaged stands rarely contained trees with adequate vigor to resist beetle attack (Mitchell and Preisler 1991).

Stands regenerating after high-intensity fires at upper elevations, particularly on north slopes, frequently began as a mixture of lodgepole pine and western larch. In those instances, outbreaks of the mountain pine beetle often provided a beneficial thinning. Many, nearly pure stands of western larch can be traced to mixed stands where the mountain pine beetle destroyed the lodgepole pine (Mitchell 1988).

Pine engraver beetle—Mountain pine beetles and pine engraver beetles also attacked young, densely stocked ponderosa pine stands (Sartwell 1971, Sartwell and Stevens 1975). Outbreaks were probably small because both species preferred trees in overstocked stands, and frequent underburning tended to keep trees well thinned and free from competition (Weaver 1957, 1967). Nevertheless, pine engraver beetles would have been abundant after light ground fires. They were attracted to scorched trees and assisted in regulating stocking below carrying capacity (Martin and Mitchell 1980, Mitchell 1990a, Mitchell and Martin 1980).

Douglas-fir engraver, fir engraver, Douglas-fir beetle—Engraver beetles—one species in understory Douglas-fir (*Scolytus unispinosus*) and another in grand fir (*S. ventralis*)—played essentially the same role as the pine engravers, removing trees scorched by low-intensity ground fires. In late-successional and climax refugia, engraver and Douglas-fir beetle populations probably increased when stocking was high, when periods of drought spanned several years, and when severely diseased trees with dwarf mistletoe or root rot were abundant. Dead trees provided needed snags and down wood. Ultimately, fuels accumulating from trees killed by diseases and insects were predisposing to severe fires, and some refugia were regenerated to seral plant communities.

Western spruce budworm, Douglas-fir tussock moth—Western spruce budworm and Douglas-fir tussock moth outbreaks occurred periodically in mixed coniferous stands of the grand fir and Douglas-fir series, long before the turn of the century. Wickman and others (1993), investigating tree-ring chronologies in the Blue Mountains, detected signatures in growth rings that clearly indicated outbreak episodes dating back to the 1700s. Similar patterns in tree rings from Colorado and New Mexico were found by Swetnam and Lynch (1989). Outbreaks were likely of short duration and small in extent (Anderson and others 1987; Carlson and others 1983, 1985; Fellin and others 1984; Wickman 1992). As noted by several investigators (Gruell 1983, Gruell and others 1982, Mitchell 1990a, Schmidt 1985, Wickman 1978, Williams and others 1980), the food base needed to generate large, prolonged outbreaks of either the western spruce budworm or the Douglas-fir tussock moth was not there. Host species stands were discontinuous, and seral species stands were continuous on most landscapes. This pattern of vegetation localized the extent and duration of outbreaks, mostly by limiting available habitat, but also by reducing dispersal potential between patches of susceptible hosts (Beckwith and Burnell 1982, Mitchell 1979). Historical outbreaks of Douglas-fir tussock moth and western spruce budworm collapsed when shade-tolerant true

firs and Douglas-fir were repeatedly defoliated, and starvation became a limiting factor in survival (Carlson and others 1983; Fellin and Dewey 1982; Mason 1974, 1977, 1981a, 1981b; Mason and Thompson 1971; Wickman and others 1973).

Although tree mortality can often be severe after a defoliator outbreak, the damage is often less than appearances would suggest. Wickman (1986) and Wickman and Starr (1990) showed that the thinning effects of defoliation and mortality, along with improved mineral cycling stemming from caterpillar frass, stimulated the growth of grand fir and Douglas-fir long after tussock moth outbreaks were over; growth even exceeded that of nondefoliated stands. Parasites and predators certainly dampen defoliator population growth during outbreaks, but their most important role seems to be in preventing outbreaks and, working with other factors, to increase the speed at which outbreaks collapse (Mason and Luck 1978, Mason and Wickman 1988, Torgersen and Dahlsten 1978, Wickman 1990).

Root diseases—Four tree-killing root diseases occurred naturally in grand fir and Douglas-fir climax forests: laminated root rot, *Armillaria* root disease, and both the P- and S-type annosum root diseases (Byler 1984; Filip 1990; Filip and Goheen 1982, 1984; Filip and Schmitt 1979; Gast and others 1991; Goheen and Filip 1980; Hadfield and others 1986; Hessburg and Flanagan 1992a, 1992b). Root diseases were a subordinate part of most presettlement, mixed-conifer landscapes; root diseases likely provided within-stand diversity where much of the structural and functional diversity was between and among stands (Cody 1975, Whittaker 1960). Root diseases produced their most visible manifestation in areas infrequently visited by fire, areas where the normal fire regime was of moderate or high severity. Such areas were mixed in composition, with seral overstories and shade-tolerant understories. Root diseases were not a threat in such forests; they increased the abundance of coverts (animal habitat focal points: locations in the forest where three or more different patch types converge) (Conlin and Giles 1973, Hunter 1990), and improved heterogeneity in size of openings, amount and shape of edge, and size of patches. The result was improved variety in habitat, forage, and edge in forests that stemmed from moderate- and high-intensity fires (Spies and Franklin 1989).

Laminated root rot—Laminated root rot infected and killed some of the highly susceptible Douglas-fir and grand fir that grew in patches missed by fire. Because the root systems of Douglas-fir and grand fir were usually well rotted, infected trees usually fell over in a jackstraw arrangement (Hadfield and others 1986). Root disease centers provided important coarse- and fine-textured gaps in forest canopies (Spies and Franklin 1989) that enhanced plant species richness (White and Pickett 1985; Whitmore 1988, 1989), and variety of habitats suitable for vertebrates (Maser and others 1979, Thomas and others 1979b). Although snags created by laminated root rot had weakened root systems and did not remain vertical for long, they were probably important as short-term snags and as logs on the forest floor, providing habitat for both raptors and their prey, and even for large animals (Bartels and others 1985, Harmon and others 1986, Maser and others 1979, Spies and others 1988, Spies and Cline 1988). Eventually, as logs decomposed and were incorporated with the soil, they became important to conifer establishment because of their moisture-holding capacity during summer drought. Logs were likewise important in mineral cycling because of their ability to harbor mycorrhizal fungi that were required in the reestablishment of conifer and perennial hardwood vegetation after fire (Harmon and others 1986, Harvey and others 1979, Maser and others 1979).

Armillaria root disease—*Armillaria* root disease ecology in turn-of-the-century forests was probably very similar to that of laminated root rot. *Armillaria* root disease probably played a role in forest succession and stand dynamics of many refugia dominated by Douglas-fir or grand fir before European settlement (Byler 1984, Hagle and Goheen 1988, Kile and others 1991). Large centers of mortality were atypical within the forest matrix where frequent underburning maintained seral species. Among seral species, this pathogen functioned as a secondary root pathogen, or as a pathogen of opportunity (Hadfield and others 1986, Kile and others 1991), attacking and overwhelming low-vigor, overmature, weakened or injured trees, as well as those stressed by drought, struck by lightning, scorched by fire, or attacked by other root

pathogens (Filip and Goheen 1982, Goheen and Filip 1980). Many of these trees would eventually become high-quality snags used by generations of primary and secondary cavity-nesting birds (Madsen 1985, Thomas and others 1979a).

Refugia dominated by Douglas-fir or grand fir were presumably found in shaded draws, on cooler north slopes, wetter, more productive sites, in riparian areas, and adjacent to rock outcroppings and talus slopes, where fires ordinarily burned with difficulty (Hessburg and Flanagan 1991, 1992a, 1992b; Lehmkuhl and others 1993; Williams and Lillybridge 1983; Williams and Smith 1991). In refugia, where Douglas-fir and grand fir colonized understories, centers of *Armillaria* root disease may have become quite large, depending on the size of the area, the density of hosts, and the fire history. Root disease severity in tolerant and resistant hosts was often magnified in these environments. Extreme disturbance associated with *Armillaria* root disease may have approached the magnitude of patchy, stand-replacement fires, where a hundred acres or more were visibly affected.

Annosum root diseases—P- and S-group annosum root disease centers were relatively uncommon in presettlement forests. These diseases require freshly cut stumps or wounds for windborne spores to infect and initiate new root-disease centers. Without tree harvesting, annosum root disease existed as a butt rot of trees with stem wounds. In central, southern, and northeastern Oregon, stands with multiple entries have been shown to have the highest frequency of mortality caused by annosum root disease and associated bark beetles (Schmitt and others 1984, 1991; Filip and others 1992a).

Dwarf mistletoes—Dwarf mistletoes would have occurred in each coniferous species, but none were particularly threatening to their hosts (Alexander and Hawksworth 1975, Parmeter 1978, Tinnin 1981, Wicker and Leaphart 1976). Given fire frequencies in historical forests, and the effects of underburning on tree composition, stocking, and canopy structure, the western larch mistletoe was likely the most prevalent and damaging. Because severe mistletoe infections in ponderosa pine provide an abundance of mistletoe brooms, fine fuels, resinous stems and branches, as well as dead trees and cankers, low-intensity surface fires would tend to torch these trees, destroying infection centers (Koonce and Roth 1980, Parmeter 1978, Weaver 1974). We suggest that crown fires often initiated in areas of severe mistletoe.

An underrated feature of dwarf mistletoes is the wildlife habitat provided by mistletoe brooms. Brooms are used for nesting, roosting, and hiding cover (Allen and Brewer 1986; Baranyay 1968; Bull and Henjum 1990; Bull and others 1989; Buskirk and others 1987; Crawford and others 1986; Farentinos 1972; Forsman 1983; Patton and Vahle 1986; Schellhaas and others, unpublished; Sever and others 1991; Smith 1982; Spencer 1987; Stauffer and Peterson 1986). Dwarf mistletoe in Douglas-fir and was probably more common on northerly aspects and in riparian areas, where the interval between fires was long. Mistletoes of seral species were probably most common on south slopes, where fires maintained seral species, and fires were usually low in intensity. High-intensity fires would eliminate mistletoe over large areas, and mistletoes would slowly re-invade from the perimeter at the rate of 10 to 15 feet a decade (Hawksworth 1958, 1960; Parmeter 1978; Wagener 1965). Birds and squirrels also contributed to reintroduction of mistletoes to those large patches (Hawksworth and others 1987, Nicholls and others 1984, Ostry and others 1983, Punter and Gilbert 1989, Tinnin and others 1982, Zilka and Tinnin 1976). Mistletoes would carry over in residual ponderosa pine and western larch overstory trees by virtue of their resistance to fire, from irregularities in fuel continuity or arrangement, or fire behavior, and the spread of these mistletoes to newly regenerating patches would be much quicker (Baranyay 1970, Parmeter 1978).

Douglas-fir dwarf mistletoe and western larch dwarf mistletoes were probably common in mid- and late-seral forests before the 20th century. Areas infested with these mistletoes tended to be the more mesic plant associations, places where fire appeared with moderate frequency (Agee and Edmonds 1991, Byler 1984, Fellin 1980, Hessburg and Flanagan 1991, Williams and Smith 1991, Williams and Lillybridge 1983, Williams and others 1990).

Mature Douglas-fir, with thick outer bark and crown bases well above the forest floor, are quite resistant to underburning. Young Douglas-fir, conversely, has thin, resinous outer bark and crowns close to the forest floor, two characteristics that enhance tree vulnerability to underburning. When mistletoe brooms occur on young trees, the likelihood of tree torching is greatly increased (Harrington 1991, Tinnin 1984, Tinnin and Knutson 1980, Wanner and Tinnin 1989). Under the right conditions of wind and weather, fires crown from mistletoe-infected understories. In addition, mistletoe brooms in Douglas-fir nullify the benefits of intertree competition and natural branch pruning by maintaining a flammable link with the forest floor. Mistletoe brooms are water and nutrient sinks nourished by the uninfected portions of trees (Fischer 1983, Hull and Leonard 1964). Mistletoe infections locally elevate cytokinin activity (Paquet 1979), thereby delaying normal senescence (Briede and others 1991).

Under historical fire regimes, Douglas-fir dwarf mistletoe was probably distributed widely but with little intensification; fire maintained open stands of ponderosa pine or mixed seral stands with Douglas-fir (Arno 1988, Fischer and Bradley 1987, Harrington 1991, Williams and Smith 1991). Douglas-fir dwarf mistletoe was probably distributed in scattered, thick-barked overstory trees that had developed on seral-dominated landscapes under the influence of frequent low-intensity fire, but further influence was minimal because understory Douglas-fir stocking was minimal. In patches where Douglas-fir was abundant in the understory, Douglas-fir dwarf mistletoe was probably abundant as well.

Western larch dwarf mistletoe was perhaps the most widespread of mistletoes in late seral stands. Of all the dwarf mistletoes, larch mistletoe survived fire in overstory western larch with the greatest constancy (Bolsinger 1978, Hessburg and Flanagan 1992b), perhaps because of larch's exceptional resistance to damage by fire (Kauffman 1991, Lotan and others 1981, Martin and Dell 1978), its resistance or tolerance to both tree-killing and opportunistic root pathogens (Filip and Schmitt 1979, Hadfield and others 1986), and the lack of primary bark beetle associates (Hessburg and Flanagan 1992a, 1992b). Conifers such as Douglas-fir or ponderosa pine with severe mistletoe infections exhibit declining crown vigor and reduced resistance, and are eventually attacked and killed by bark beetles and opportunistic root pathogens like *Armillaria* root disease (Hadfield and others 1986, Morrison and others 1991), and occasionally P-group annosum root disease (personal observation, P. Hessburg).

Larch mistletoe brooms are weak and brittle and frequently break off when still relatively small. Under historical fire regimes, branch litter accumulating under infected hosts caused lethal fire scorching of some infected trees (Alexander and Hawksworth 1975, Tinnin and others 1982, Wicker and Leaphart 1976). According to Tinnin and others (1982), the increased burn potential accentuated the advantage of fire-adapted species such as western larch.

Severe effects from lodgepole pine dwarf mistletoe were localized because of frequent fire return and the sanitizing effect of fire. Recurring fires eliminated fire-sensitive lodgepole pine and its mistletoe (Martin and Dell 1978, Williams and Lillybridge 1983, Williams and Smith 1991). Stand-replacement fires in lodgepole pine at intervals of less than 150 to 200 years perpetuated nearly pure patches of lodgepole pine or mixed seral stands with a major lodgepole pine component (Lotan and Perry 1983, Williams and Lillybridge 1983, Williams and Smith 1991). Stand-replacement fires in lodgepole pine stemmed from prior mountain pine beetle outbreaks and associated fuel buildup (Amman 1991, Brown 1975, Fellin 1980). Lodgepole pine dwarf mistletoe infested replacement stands from the perimeter, where complete sanitation by fire occurred (Parmeter 1978), and from within (Baranyay 1970) when individual infested trees or islands of trees survived fires and subsequent bark beetle attacks.

Current Forests

The century since the advent of fire protection has seen a steady shift away from historical parklike ponderosa pine and larch stands toward denser late successional stands. Lacking the low-thinning effect of frequent underburning, many stands were invaded by nearby grand fir and Douglas-fir. Driven by short-term economic goals, the harvesting of high-valued overstories accelerated the conversion to insect- and

pathogen-susceptible late successional forests. In some landscapes, only a few of the original seral overstory trees remain; in others, the conversion is complete. The harvest supported mills and stabilized populations in many small towns, but the economic success could not be sustained. The stands of large ponderosa pine and western larch began to disappear, and so did other supporting ecosystem components. Wickman and others (1993), in their review of forest inventory reports for the Blue Mountains, showed that the amount of forest land dominated by ponderosa pine declined from 80 percent (all ownerships) in 1936 to about 25 percent in 1992.

Williams and others (1980), comparing the location of Douglas-fir tussock moth outbreaks with 1935 Forest Service timber type maps, showed that 80 percent of the infestations in the worst outbreak areas (east-central Oregon and northeastern Washington) occurred in stands once classified as ponderosa pine type. In the Blue Mountains of northeastern Oregon and southeastern Washington, some 30 to 40 percent of the tussock moth outbreaks were in stands once dominated by ponderosa pine. This relation between rising insect and pathogen populations and the shift toward overstocked climax forests is consistent throughout the east side of Oregon and Washington, but the low- to mid-elevation climax grand fir and Douglas-fir forests have sustained the most damage.

Western pine beetle—The western pine beetle continues to threaten ponderosa pine in forests east of the Cascades, even though many of the large stands of older pine, once a dominant signature of eastern forest landscapes, are gone (Scott 1991). In heavily logged areas, the few large ponderosa pine trees that remain in the overstory are often old and decadent, with poor crowns and generally poor vigor. In landscapes still dominated by overstories of ponderosa pine, sanitation salvage entry has often been restricted and veteran trees with poor crowns and poor vigor have accumulated. Such trees attract beetles and generate outbreaks (Salman and Bongberg 1942, Wickman and Eaton 1962). Lacking regular fire, dense understories of shade-tolerant species compound the problem of declining vigor of overstory ponderosa pine by increasing intertree competition for soil moisture and nutrients. Because of the declining vigor of overstory ponderosa pine, both *Armillaria* root disease and the P-group *annosum* root disease are more prevalent in pine than before, and both invite attack by the western pine beetle. The current drought has influenced western pine beetle populations by increasing the number of trees available for attack. Dead tree fuels, coupled with dense, live, shade-tolerant understories, have created a dangerous accumulation of fuel for conflagrations, now a serious threat to many eastside forests.

Mountain pine beetle—The mountain pine beetle is probably the most influential bark beetle in current grand fir and Douglas-fir climax forests. It damages overstocked, pole-sized ponderosa and lodgepole pine. On good sites, the beetle is a minor influence on second-growth ponderosa pine (Sartwell 1971). Because ponderosa pine grows best in the grand fir series (Daubenmire 1952) and because the number of pines is reduced there, the mountain pine beetle is a minor problem of ponderosa pine at higher elevations. The beetle has been a major influence in drier forest landscapes downslope, where young stands are often overstocked and stressed (Sartwell and Stevens 1975). Mountain pine beetle infestations can be particularly serious when lodgepole pine is intermixed or when a mature stand of lodgepole pine is nearby (Mitchell 1988). Lodgepole pine can generate substantial populations of the mountain pine beetle, and large beetle populations can overwhelm nearly any tree, particularly when beetles are drawn to stands by low-vigor or lightning-struck trees (Mitchell 1987).

The mountain pine beetle shows a decided preference for lodgepole pine (Mitchell 1988). On good sites, when lodgepole is mixed with ponderosa pine, the only ponderosa pines attacked are those a few feet away from attacked lodgepole pines. Outbreaks of the mountain pine beetle are most severe where pure or nearly pure stands of lodgepole pine are present; the grand fir series has many such stands. Enormous outbreaks have been recorded throughout western North America (McCambridge and others 1979); some of the most severe have been in interior forests of Oregon and Washington (Burke 1990, Mitchell 1988, Scott 1991, Wickman 1990).

Current outbreaks of the mountain pine beetle in lodgepole pine are probably more frequent, more extensive, and more severe than at any time in history (Mitchell 1988). An outbreak in a typical stand will kill 200 to 300 lodgepole pines per acre before it is finished. Oddly enough, most of the trees killed are not very susceptible to beetle attack. Rather, the beetle focuses on 50 to 60 trees larger than 9 inches d.b.h., and other nearby trees are killed somewhat randomly, depending on how close they are to the trees that are the object of attack (Geiszler and Gara 1978; Mitchell and Preisler 1991; Preisler and Mitchell, in press). After 15 to 25 years, many beetle-killed trees are on the ground (Harvey 1986, Mitchell 1990b). Before the era of fire control, those trees would have been the fuel for the next conflagration that regenerated lodgepole pine, and it would have been another 100 years before another outbreak was possible. With fire protection, lodgepole pine stands may suffer two or three outbreaks of the mountain pine beetle before an outbreak is interrupted by fire. Advance lodgepole pine regeneration remaining after an outbreak that is not followed by fire becomes the new stand for the next outbreak. In this sequence, the large trees needed to generate an outbreak are available in about 50 years instead of 100 years (Mitchell 1987).

Another consequence of fire protection in lodgepole pine is a reduction in landscape diversity. Outbreaks in modern times simultaneously affect more stands than historically, thus generating larger beetle populations (Mitchell 1988). Beetle outbreaks cycle faster because of advance regeneration, cover larger areas, and—with larger beetle populations—kill more trees. Fuels accumulating from multiple beetle outbreaks generate fires of extreme intensity and great landscape scale.

Pine engraver beetle—The pine engraver beetle is doubtless more abundant and destructive now than in past centuries. This beetle focuses on small and stressed trees (Sartwell 1970), and eastside forests now have more of both than ever before. Damage is most severe on poor, dry sites. The most significant outbreaks today occur in low-elevation ponderosa pine climax forests. More discussion in the next section addresses insects and pathogens of the ponderosa pine series.

Douglas-fir beetle—Since the advent of fire control, the Douglas-fir beetle has become a more frequent influence in Douglas-fir and grand fir climax forests. Douglas-fir is now much more abundant, and trees weakened by extended outbreaks of the western spruce budworm or Douglas-fir tussock moth are susceptible to attack by the beetle (McGregor and others 1983, Scott 1991, Wright and others 1984). Currently, some of the most serious damage is associated with large trees growing in riparian areas and along ridgetops. Trees in these environments have escaped large fires and consequently are some of the oldest Douglas-fir on the landscape. Trees in riparian environments are probably sensitive to drought as well. As the Douglas-fir regenerated or released in this century ages, the threat of the Douglas-fir beetle will also increase.

Fir engraver—The fir engraver normally attacks low-vigor trees: those weakened by overstocking, root disease, lightning strikes, and drought. Conditions suitable for this beetle certainly occurred in scattered stands before this century, but not to the extent that they are today. From what we know of the historical role of fire, grand fir and white fir, favorite hosts of the fir engraver, have never occurred in such abundance. They are widespread throughout the grand (white) fir series, as are low-vigor growing conditions. The current influence of fir engraver is very large, and it continues to expand in response to increasing root disease, dwarf mistletoe, overstocking, persistent drought, and severe defoliation by budworm and tussock moth populations (Wright and others 1984). This drought will inevitably end, but without management actions to restore widespread seral conditions, the supply of host fir will remain, and disease and insect influences will persist.

Western spruce budworm, the Douglas-fir tussock moth—The most dramatic and visually displeasing insect disturbance pattern associated with the increasing shade-tolerance of eastside forests is that caused by the western spruce budworm and the Douglas-fir tussock moth. The ecology and dynamics of both insects have been studied for many years (Brookes and others 1978, 1985, 1987; Mason 1974, 1977, 1981a, 1981b; Mason and Wickman 1988; Wickman 1978; Wickman and others 1992). Spruce budworm

larvae feed on new growth and move to old needles (with poor survival) only when the supply of new growth is exhausted. Because old needles can sustain defoliated trees for a time by providing photosynthate for production of new foliage, budworm can survive in a grand fir stand for 5 to 11 years before running out of food. Douglas-fir trees can endure defoliation longer than other trees because they generate new foliage from adventitious buds (Van Sickle 1987).

When susceptible stands were scattered, outbreaks probably collapsed when the local food supply was exhausted. Currently, with an increasing abundance of susceptible stands close to each other, larvae (Beckwith and Burnell 1982) and moths can disperse from stand to stand with minimal loss and with a good chance of finding a new food supply. If the food supply is large and close enough to other host stands, populations can cycle back and forth between stands, chronically defoliating for years. Because most of Oregon and Washington east of the Cascade crest is in a climatic region suitable for western spruce budworm populations (Kemp and others 1985), the problem of chronically long defoliator outbreaks will likely continue for a long time, and outbreak damage severity will likely worsen as susceptible forests are allowed to age.

Like the western spruce budworm, Douglas-fir tussock moth populations respond to widespread changes in forest vegetation composition and vertical structure. Tussock moth larvae also feed on true firs and Douglas-fir, and prefer new needles to old. Late-instar tussock moth larvae, however, feed readily on old needles, and large populations can completely defoliate trees in 1 year and cause mortality in 2 to 3 years (Wickman 1978). Accordingly, damage by tussock moth feeding is often more severe than budworm damage, although severe tussock moth damage tends to be localized, and budworm damage is much more extensive. The western spruce budworm is almost always present in numbers large enough to sample; tussock moth on the other hand, is either found in great numbers or is barely detectable (Mason 1987). We do not know whether the increasing dominance of shade-tolerant species in eastside landscapes will affect the severity or duration of tussock moth outbreaks, but outbreaks will occur in places where no hosts were growing 100 years ago.

Annosum root disease—In the current fire-restricted condition, all major tree-killing root diseases except P-group annosum (Chase 1989, Orosina and Cobb 1989) are widespread, after landscape colonization by grand fir and Douglas-fir (Baker 1988, Byler and others 1990, Filip and Goheen 1984, Hagle and Goheen 1988, Hessburg and Flanagan 1992a). Collectively, effects of root diseases on growth and mortality, and their contributions to flammable fuels are ecologically significant. Most surprising is the rate of increase in S-group annosum root disease in grand (white) fir. Grand fir climax forests contain large increases in S-group annosum because grand fir stumps were infected by spores when stands were logged (Filip and others 1992a, Hadfield and others 1986, Orosina and Cobb 1989). New centers of annosum root disease mortality are emerging throughout the grand fir climax forest, especially where large grand fir were first harvested. Over the next 15 to 20 years, a large increase is likely in the number of new S-group annosum root disease centers corresponding with the most recent partial-cutting entries in merchantable grand fir (Gast and others 1991; Schmitt and others 1984, 1991). Infection centers will continue to expand until fire or silvicultural activities create conditions for the reintroduction of seral species.

Pine stumps created after logging were infected by spores of both the P- and S-group annosum diseases. Because S-group isolates are primarily pathogenic on true firs and spruces, the roles these stumps will play in the future incidence of disease is uncertain. Pine stump infection by P-group annosum is often high in Douglas-fir and grand fir climax forests, but mortality in ponderosa pine is uncommon. Without prolonged warming of the climate, we predict that growing conditions for ponderosa pine in these series are adequate to sustain resistance to this root disease. In the event of prolonged global warming, however, P-group annosum may become more serious on what are now mesic sites of the Douglas-fir and grand fir series. P-group annosum effects are currently most serious on dry pine sites of the ponderosa pine climax series. Nevertheless, the current drought has depressed the vigor of pines on some drier Douglas-fir and grand fir climax sites, and small P-group annosum centers have been observed (Hessburg and Flanagan 1991, 1992a, 1992b).

Armillaria root disease, laminated root rot—Both *Armillaria* root disease and laminated root rot have expanded their influence from historical infection centers that colonized burgeoning populations of Douglas-fir and grand fir, and both diseases are now epidemic in many parts of the Douglas-fir and grand fir climax forest. Pathogen and insect populations are building in response to increasing availability of preferred hosts in vertical and horizontal arrangements that are optimal for dispersal.

Dwarf mistletoes—With the restriction of fire, at least 43 percent of the Douglas-fir east of the Cascades is infected with dwarf mistletoe (Bolsinger 1978; Hessburg and Flanagan 1992a, 1992b). Infections are more widely distributed and more severely damaging than ever before. As the abundance of true firs increased, so did the abundance of dwarf mistletoes in true firs, where 21 percent of true fir stands are infected (Bolsinger 1978). Damage is most severe in central Oregon, where dwarf mistletoe is associated with canker fungi that weaken trees, predisposing them to further attack by fir engravers (Filip 1984).

Indian paint fungus—Stem decay of grand fir, especially decay caused by the Indian paint fungus, and butt rot caused by *H. annosum* (Aho and others 1987) are widely distributed throughout mixed conifer landscapes where true firs were not characteristically dominant or abundant. Stem-decay pathogens are essentially pioneering new habitats only recently colonized by their hosts. *Heterobasidion annosum* is competing with *Echinodontium tinctorium* as the dominant decay agent of grand fir (Filip and others 1992b), perhaps because of increased harvesting of mature and overmature true fir. The Indian paint fungus commonly sporulates on the boles of mature and overmature trees, but *H. annosum* fungus sporulates in the hollows of large stumps.

PONDEROSA PINE SERIES

Ponderosa pine climax forests are distributed throughout eastern Oregon and Washington. They occupy a narrow band running the length of the Cascade Range on the lower slope; spread eastward into the central Oregon pumice plateau; ring large areas of the Blue, Ochoco, and Wallowa Mountains in eastern Oregon and southeastern Washington; and cover extensive areas of the Okanogan Highlands in northeastern Washington (Franklin and Dyrness 1973). The ponderosa pine series occupies the lowest elevations and the hottest, driest environments where ponderosa pine grows in the eastern Oregon and Washington. Above, the ponderosa pine series intergrades with the Douglas-fir, grand fir, and white fir series, depending on the locale. Below, it merges with the sagebrush desert, desert grasslands, and western juniper or Oregon white oak woodlands. The poorest sites for ponderosa pine are at the lower end of this series where ponderosa pine is in tension with other desert species.

Historical Forests

Western pine beetle—This series is well known in historical journals and photographs for its wide-open ponderosa pine stands. Fire scars on large, old pines reveal that low-intensity ground fires commonly burned at intervals of 15 years or less (Bork 1984, Martin and Dell 1978). In this series, young ponderosa pine or fire-sensitive associates like western juniper or lodgepole pine, invaded recently burned stands, but they seldom survived (Munger 1917). Because of the dominance of large, old ponderosa pine and poor growing conditions, the western pine beetle was probably a greater threat in this series than in either the grand fir or Douglas-fir series. Miller and Keen (1960) noted extensive killing by this beetle throughout the ponderosa pine climax forest, especially during the great drought of the 1920s and 1930s.

Mortality caused by the western pine beetle was probably more or less continuous, even in years of adequate soil moisture. In stands dominated by old trees, a few trees each year were always too weak to produce adequate oleoresin exudation pressure to pitch out beetles. In addition, lightning-struck pines were fairly common, inviting attacks by the western pine beetle (Hepting 1971, Martin and Mitchell 1980, Miller and Keen 1960, Mitchell and Martin 1980). In the long run, this mortality was probably important for continued healthy ecosystems for the snag and log habitat provided (Mitchell and Sartwell 1974).

Bark beetle outbreaks probably occurred frequently in the tension zone where forest and desert influences intergraded, and were likely events that correlated with climate flux. In this moisture-limited soil environment, trees were small-diametered and short when young, and the struggle to survive from year to year with only marginal rainfall invited attacks on the least vigorous by the mountain pine beetle and the pine engraver beetle. These two beetles were also important in areas missed by underburning, where residual tree densities were above long-term carrying capacities.

Pandora moth—Ponderosa pine has many associated defoliating insects, but few were historically significant. The best known defoliator of ponderosa pine is the pandora moth, an insect with a long history of attacking ponderosa pine throughout the high pumice plateau of Oregon (Furniss and Carolin 1977). It is best known as the largest insect attacking western conifers: caterpillars can be 2 inches long, and moths have wingspans of 2.5 inches. Caterpillars feed exclusively on old needles and have an unusual 2-year life cycle, with defoliation only in alternate years (Schmid and Bennett 1988). Defoliation in the feeding years can be spectacular and some older trees are apparently killed when bark beetles attack defoliated trees (Patterson 1929). Mortality is rare in younger trees (Mitchell 1989) and seems to be confined to trees suffering from severe mistletoe infections and attacks by pine engraver beetles (Wagner and Mathiasen 1985). Defoliation occurs in patches of 5 to 40 acres, and when defoliation has run its course, caterpillar frass on the ground may be up to a 1/2 inch deep. This nutrient boost to the soil must be important to soil microbes and nutrient cycling (Crossley 1977).

Other defoliators—Numerous other insects have been recorded as infesting ponderosa pine and even killing a few trees. Examples are the pine butterfly, several sawflies (Hymenoptera/Diprionidae), needle and tip miners (Lepidoptera/Tortricidae), and another budworm, the sugar pine tortrix. Ponderosa pine associations with these insects were not historically important in presettlement forests, nor are they significant problems today (Furniss and Carolin 1977).

Annosum root disease, Armillaria root disease—Before the era of resource management, P-group annosum root disease distribution was scattered. Under the influence of regular underburning, stocking was normally low relative to current conditions, and natural intertree spread was restricted by low tree density. The driest sites of the pine series were most severely damaged. Western juniper and ponderosa pine were both hosts to this variant of annosum root disease. Armillaria root disease was an opportunist of fire-scarred, overmature, stressed, damaged, or weakened ponderosa pine in the series.

Comandra rust, Elytroderma needle disease—Comandra rust and Elytroderma needle disease were locally significant in ponderosa pine on occasion but never threatening to entire pine landscapes. Comandra rust topkilled mature and overmature ponderosa pine over many years, providing nesting trees for raptors building stick nests. Topkilled trees typically developed a resin-soaked, case-hardened dead top, ensuring a durable habitat with a long residence time.

Western dwarf mistletoe—Western dwarf mistletoe was most damaging to ponderosa pine on dry sites such as these. Severely infected trees would torch during underburning events. Frequent underburning minimized the accumulation of fuels and the likelihood of stand-replacing events. As a result, dwarf mistletoe was seldom eliminated from pine stands by fire, but frequent underburning sanitized ponderosa pine stands by torching the most infected trees, eliminating infected understories and other ponderosa pine of insufficient bark thickness. Frequent low-intensity fires elevated crown bases and simplified canopy structure, directly influencing mistletoe spread. Simplifying canopy structure and reducing stem density reduced the probability of mistletoe seed dispersal to susceptible understory hosts and lateral spread among trees. On balance, many ponderosa pine stands had a modest amount of mistletoe, but mistletoe severity was continuously reduced by the influence of fire.

Current Forests

Western pine beetle—Intraspecific competition in ponderosa pines for light, water, and nutrients can continue for decades, but the contest has no winners (Barrett 1979). Without underburning fire or a silvicultural thinning to weed out excess trees, a stand of ponderosa pine can stagnate for decades without much detectable growth. Eventually stand vigor declines, and the effects of various stresses, including drought and root disease, accumulate, which invites bark beetle attacks on overstory and understory trees. Site potential is more easily exceeded in the ponderosa pine series than elsewhere. Ponderosa pine sites are poor for tree growth, and even moderate increases in stocking invite beetle attack.

Any large increase in understory pine abundance stresses that cohort of pines, and the overstory trees as well. The western pine beetle is currently responding to these very conditions and to the current drought, and beetle-killing of the larger trees has increased markedly in the last few years. As elsewhere, the simultaneous increase in P-group annosum root disease distribution is compounding the attractiveness of various stands to beetle attack.

Mountain pine beetle, the pine engraver—One serious problem that is emerging in many dry, central Oregon ponderosa pine stands stems from logging at these lower elevations between 1910 and 1940. Natural regeneration almost always exceeded the carrying capacity of these sites. Trees on naturally regenerated, cutover sites are now large enough for attack by the mountain pine beetle and the pine engraver. The first indications of future problems are visible on some of the poorest sites. Intertree competition is severe and mountain pine beetles—and sometimes, western pine beetles—are beginning to take advantage of the reduced vigor in these trees (Barrett 1979, Larson and others 1983, Sartwell and Stevens 1975). In extreme situations, particularly in years of below-normal spring rainfall, the pine engraver beetle causes mortality in young, overstocked stands (Dolph 1971).

Lacking regular low-intensity fires, lodgepole pine is invading many dry, ponderosa pine climax stands. This invasion presents two problems: first, without fire to remove lodgepole pine, the invading species tends to dominate stands within a few decades (Munger 1914); second, the presence of lodgepole pine invites attack by the mountain pine beetle, increasing the likelihood that ponderosa pine will be killed along with lodgepole pine (Mitchell 1988). In some locations, harvest of the overstory ponderosa pine is aggravating the problem, leaving no natural seed source for regeneration of ponderosa pine.

Annosum root disease—Another serious result of current management practices has been the visible increase in the distribution and severity of the P-group annosum root disease (Goheen 1983, Goheen 1993, Hopkins and others 1988). Marginally commercial ponderosa pine sites have been selectively logged, leaving abundant stumps that have been infected by spores. Two or more decades later, these stumps function as new disease centers. The increase in inoculum is compounded by high tree densities, which increase the probability of successful intertree spread of disease. Under managed conditions, pine sites with productivity ratings less than about $30 \text{ ft}^3 \cdot \text{acre}^{-1} \cdot \text{yr}^{-1}$ have the highest incidence of this root disease. Disease severity on some sites is now great enough that mortality rates reduce site productivity below the level of $20 \text{ ft}^3 \cdot \text{acre}^{-1} \cdot \text{yr}^{-1}$ required to be classified as land suitable for timber harvest.

Western dwarf mistletoe—Western dwarf mistletoe currently infests about 26 percent of ponderosa pine east of the Cascades. We suspect this recent measure of incidence (Bolsinger 1978) is elevated from historical times. Fire had beneficial effects on canopy structure and tree density that discouraged survival and dispersal of this mistletoe (Koonce and Roth 1980).

LOGGEPOLE PINE SERIES

Where it occurs as a climax dominant, lodgepole pine is an edaphic climax species rather than a climatic climax species. Most stands of climax lodgepole pine are found on the high pumice plateau of central Oregon, where in some locales spring temperature regimes at the time of seedling establishment discourage survival of all tree species except lodgepole pine. There, mile after mile of pure lodgepole pine stands are found on cold air flats, where growing-season temperatures can be 4.5 °C colder than adjacent ponderosa pine-covered slopes (Cochran 1984, Cochran and Berntsen 1973).

Mountain pine beetle—As in the other series, the primary disturbances regulating the ecological character of lodgepole pine landscapes were historical wildfires and mountain pine beetle outbreaks. Stands with 30 to 80, 9-inch-d.b.h. or larger trees were susceptible to beetle attack. Mountain pine beetle outbreaks often killed as many as 250 trees per acre, creating an enormous quantity of flammable fuel (Mitchell 1988). Subsequent fires destroyed remaining stands, allowing regeneration of lodgepole pine. What is unique in central Oregon is that the environment for tree growth is so constraining that each new stand will always be lodgepole pine; no other species can compete successfully. Without fire or aggressive stocking control and regeneration programs, overmature and overstocked lodgepole pine stands will always provide appropriate conditions to initiate and carry a mountain pine beetle outbreak.

One variation on the fire and bark beetle cycle is found on the very poorest lodgepole pine sites in central Oregon. Geiszler and others (1984) found a site so poor that it had virtually no understory vegetation. Meager fuels supported only meandering, pencil-like burns that smoldered along downed lodgepole pines killed years earlier by the mountain pine beetle. Pencil burns rarely killed trees, but they did scar tree bases. Scars were entrance points for decay fungi which, years later, predisposed affected trees to beetle attack (Gara and others 1984). Presumably, poor lodgepole sites like these are a kind of refuge for the mountain pine beetle, a place of continuous low activity.

The pattern of mountain pine beetle outbreaks described for the grand fir and Douglas-fir series is essentially the same as that found in the lodgepole pine climax forest, but because lodgepole-dominated landscapes are much more extensive in central Oregon, lack of fire has created a vastly larger area of mature and overmature stands. When an outbreak is initiated in central Oregon, it will produce more beetles, kill more trees, and operate over larger landscapes, generating heavy fuel accumulations over vast, continuous areas. Wildfires in central Oregon's beetle-killed lodgepole pine forests have the potential to be among the most severe fires ever.

Pandora moth, lodgepole needle miner—The pandora moth has been observed defoliating lodgepole pine, usually in association with infestations on ponderosa pine. Another insect of some significance in the lodgepole pine series is the lodgepole needle miner. Outbreaks are uncommon, but they can be very destructive. Mason and Tigner (1972) and Tigner and Mason (1973) showed that vigorous stands on productive sites were most resistant to population buildup. Young trees less than 10 years old also resist infestations. Prolonged outbreaks have occurred in the central and southern Sierra Nevada of California, where the cumulative effects of prolonged needle mining were complete defoliation and widespread tree mortality. In central Oregon, populations are higher on some sites than others, but damage is usually light or moderate.

Western pine shoot borer—Still another insect enemy of lodgepole pine is the western pine shoot borer. A common terminal miner in central Oregon and perhaps elsewhere, it is occasionally responsible for considerable height-growth loss and stem deformities throughout the range of lodgepole pine (Mitchell and Sower 1991). This insect, like many others, has probably been a regular enemy of lodgepole pine, and the frequency and pattern of damage has probably changed little over the years.

Lodgepole pine dwarf mistletoe—Dwarf mistletoe was often severe in premanagement-era lodgepole pine landscapes. The amount of mistletoe was highly correlated with boom-and-bust fire cycles characteristic of the series. Over long periods without fire (100 to 200 years), mistletoe severity would often be high, depending on the pattern of the last fire event. After fire, mistletoe reinvasion was rapid when islands of live, mistletoe-infected lodgepole pine were scattered throughout the burned area. Slow reinvasion was the pattern when fires were large and intense, resulting in near total stand destruction; then new infections came from diseased trees on distant perimeters, or from chance introductions by birds and small mammals.

On balance, dwarf mistletoe in lodgepole pine is more widely distributed than historically. Lacking nearly a century of cleansing fires, most mistletoe-infected stands of a century ago are still infected. More than 100,000 acres of lodgepole pine in central Oregon, and uncounted thousands of acres elsewhere, have been destroyed by the mountain pine beetle in the last 20 years. Beetle outbreaks killed only the largest trees, encouraging release of residual trees and development of uneven-aged stands. These two features—carryover of mistletoe infections from a prior generation of trees and development of multiple canopy layers—are optimal for the spread of dwarf mistletoe.

Atropellis canker, western gall rust, stalactiform rust—Atropellis canker, western gall rust, and stalactiform rust are widespread and sometimes locally significant. Atropellis canker and gall rust severity are associated with overstocked lodgepole pine in sites with cool air ponding.

SUMMARY AND CONCLUSIONS

Human activities that contributed to declining health of forests east of the Cascade crest in Oregon and Washington began in the West before the turn of this century with efforts to control wildfires. Early logging of premium quality seral species began before the start of this century, and continued to World War II in some locales. Extensive, economically motivated, selective harvesting of high-value ponderosa pine, western larch, western white pine, sugar pine, and Douglas-fir began after World War II and has continued to some extent to the present day. Fire suppression and control policies favored increasing stand densities and the regeneration of shade-tolerant and fire-intolerant species.

Effective fire exclusion and selective harvesting in all of its forms accelerated forest succession in all major, forested, climax series. The short-term benefits of an effective fire-control policy and selective harvesting apparently justified those management decisions. Clearly, historical management activities have produced unstable ecosystems, excessively damaging pathogen and insect populations, and vegetation conditions that cannot be sustained in the long term. The following is a brief summary of the most important outcomes:

- ❑ Density has significantly increased and vigor has decreased in many lodgepole pine, ponderosa pine, Douglas-fir, and grand fir (white fir) climax forests.
- ❑ Extensive areas of the Douglas-fir, grand fir (white fir), and subalpine fir series are dominated by shade-tolerant species.
- ❑ Landscapes (rather than patches) are susceptible to defoliator and bark beetle outbreaks in the lodgepole pine, ponderosa pine, Douglas-fir, and grand (white) fir series.
- ❑ Landscapes (rather than patches) are susceptible to high-intensity, stand-replacement fires in the lodgepole pine, ponderosa pine, Douglas-fir, and grand (white) fir series.
- ❑ The threat of catastrophic fire to subalpine fir, Pacific silver fir, western hemlock, western redcedar, and mountain hemlock series is increased through the increase in fire hazard in nearby lodgepole pine, ponderosa pine, Douglas-fir, and grand (white) fir climax forests.

- ❑ The threat of defoliation to subalpine fir, Pacific silver fir, western hemlock, western redcedar, and mountain hemlock series is increased through enhanced continuity of susceptible host types.
- ❑ The duration, extent, and severity of defoliator and bark beetle outbreaks have increased with the increased quality, uniformity, and continuity of host types.
- ❑ Conditions for nearly optimal spread of root diseases and dwarf mistletoes exist in many parts of the lodgepole pine, ponderosa pine, Douglas-fir, and grand (white) fir climax series.
- ❑ Insect and disease growth and mortality effects are increasing fuel loads at an alarming rate.
- ❑ Wildlife habitat conditions and populations have developed that are unprecedented, according to historical fire disturbance patterns, and are nonsustainable in the long-term throughout significant areas of the east side.
- ❑ The pattern of landscape diversity is anomalous for many forests of the lodgepole pine, ponderosa pine, Douglas-fir, and grand (white) fir climax series. Landscape diversity of subalpine fir, Pacific silver fir, western hemlock, western redcedar, and mountain hemlock climax forests has been affected but to a lesser degree.

Specific solutions to these problems are complicated by the variety of sites where restoration or rehabilitation is needed, but a few broad goals are obvious:

- ❑ Stocking should be reduced on forested acres where long-term carrying capacity is exceeded. This change can be accomplished silviculturally and with the judicious use of fire and other management tools. Many eastside lodgepole pine and ponderosa pine forests are moisture-limited, and site resources are particularly limiting. As long as excess trees and intertree competition depress vigor, effects of bark beetles, root diseases, and dwarf mistletoes will be exaggerated.
- ❑ Throughout the Douglas-fir and grand (white) fir series, the shift toward late-successional stands of shade-tolerant species should be reversed, with the goal of restoring a seral-dominated forest matrix. Historical stands and landscapes were more tolerant of fire than current landscapes. Underburning fire, once common and influential to low- and middle-elevation forests, is now unlikely.
- ❑ Management activities should promote restoration of landscape patterns that emulate historical variability. The landscape pattern of species composition, vegetation density, canopy structure and cover, stand (patch) size and shape, and patch adjacency have been significantly altered in this first century of management (Lehmkuhl and others 1993), but the former pattern is recognizable with careful study. The historical picture of the east side is one of regular fire disturbance; fire-adapted species and fire-adapted landscapes were favored. Alternative trajectories for eastside landscapes are certainly possible, but as yet nothing is known about their characteristics or efficacy. With that significant knowledge gap, managing toward vegetation conditions that are known to have been sustained seems appropriate, rather than managing toward conditions that are potentially unsustainable.

Managing for landscapes exactly as they were in presettlement times is probably unwise. The repeated light underburns characteristic of presettlement times, for example, probably reduced the growth potential of ponderosa pine (Cochran and Hopkins 1991, Landsberg and others 1984). Intentional fire-setting by Indians also increased underburning, frequently resulting in more fire-tolerant vegetation than might have otherwise occurred (Robbins and Wolf 1993). Until the view of what the future forest should look like is clearer, forest landscapes dominated by seral stands ought to be what managers aim for. Clearly, seral

ecosystems are more amenable to management than those approaching climax. Experiments should test alternative landscape constructions on public lands. We offer some specific suggestions for managing vegetation where highly influential insects or pathogens may be threatening:

Pine bark beetles—Pine bark beetles normally attack low-vigor trees, especially those weakened by diseases, drought, or lightning strikes; this role is not their current one. Many pine stands now have more trees per acre than site resources can support. Competition weakens the competitors, and bark beetles have evolved an attack strategy that takes advantage of weakness. Overstocked stands should be thinned, and the ingrowth of shade-tolerant conifers should be discouraged throughout the rotation (or life history) of a patch, unless that understory is vital to a particular habitat and can be sustained in the long term given historical fire regimes. Beetles appear to be discouraged by the physical environment of thinned stands, and improved vigor in residual trees is a deterrent against attacks (Preisler and Mitchell, in press). Lodgepole pine will not tolerate light ground fires, so machine or hand thinning seems to be the solution. Ponderosa pine can be thinned either by prescribed burning or by hand or machine thinning.

Douglas-fir beetle and fir engraver—The best solution for both insects is to reduce the abundance of host trees or, more directly, to manage for seral landscapes. Where late-successional or climax patches are desired as landscape components, and these desires are consistent with historical fire regimes, insect and disease effects will often be considered as benefits.

Douglas-fir tussock moth and western spruce budworm—These defoliators will go where their hosts are plentiful. Landscape patchworks that are seral-dominated but include late-successional and climax habitats will be defoliated. That defoliation will rarely threaten sustainability, however, which is as it should be for low populations. Landscapes dominated by shade-tolerant species will also be defoliated, but this defoliation will threaten sustainability. Stability will ultimately be restored to these landscapes by conflagration. When managers consider landscapes for rehabilitation, particular emphasis should be placed on dry Douglas-fir and grand fir climax sites where defoliation is most severe. On more mesic landscapes, interim solutions may be required. Some grand fir and Douglas-fir forests are within two or three decades of harvest; for them, decisions might be to protect some with biological insecticides until they can be harvested and regenerated to seral species. Economic costs and benefits of insecticide use should be analyzed. Other options for managing commercial stands susceptible to the western spruce budworm are to thin (Carlson and others 1985b), or thin and fertilize (Mason and others 1992, Wickman and others 1992). Budworm will attack such stands but damage to trees may be slightly reduced.

Root Diseases—The pathogens that cause laminated root rot, *Armillaria* root disease, and *S-group annosum* are widely distributed throughout the east side, but of concern to management is disease that has developed in areas colonized in this century by their hosts. Management activities that restore the dominance of seral species to the Douglas-fir and grand fir climax forests, where that is ecologically appropriate, will effectively manage effects of root diseases. Root diseases will not disappear, but growth and mortality effects, and associated bark beetle effects, will be diminished.

To manage root diseases effectively in a particular area, the geographic distribution of each root pathogen must be determined in its various inoculum structures (stumps, snags, standing dead trees, and live trees with and without symptoms). Root disease inventories are needed, and plant associations or plant association groupings should be characterized for root disease hazard. Host damage characteristics (that is, tree species affected, size and age classes affected) must also be determined in each unique locale because the ecology of root diseases varies by locale. The most ecologically sound management will usually be to favor tree species that are less susceptible to infection and mortality (Hadfield and others 1986). This strategy can be accomplished silviculturally and with the use of prescribed fire. Stocking control in pure species stands may also decrease damage from some root diseases.

Stem decays—Thin-barked, nonresinous tree species are more decay-prone than are resinous species, and can be discriminated against during silvicultural operations in mixed-conifer stands. In commercial applications, damage caused by stem decay fungi can be reduced through shortened rotations and with wound prevention. These preventive steps are critical, especially if advance regeneration is already infected and some decay is present. Nondestructive sampling methods for determining the extent of infection and decay by the Indian paint fungus have been developed for white and grand fir (Filip and others 1983) and may be applicable to other coniferous hosts. Wound-prevention guidelines are available and can be applied, both in harvest planning and during woods operations, to prevent wounding and associated stem decay.

Dwarf mistletoes—Most dwarf mistletoes are highly host specific. Rapid spread of mistletoes is favored by pure stands of host trees and multilayered canopies. Even-aged or single-storied stands can be managed with low and moderate mistletoe infestation. Mistletoe infection can be completely avoided by favoring nonsusceptible species in mixed-conifer stands. Stocking control and removal of the most severely infected trees has also been shown to reduce damage in several coniferous species (Barrett and Roth 1985, Filip and others 1989, Knutson and Tinnin 1986). That reduction in severity is consistent with sanitizing effects of historical low- and moderate-intensity fires.

Healthy forests must be designed. Managing forested landscapes is a giant experiment with a moving front. Management must sight on the far horizon, and make adjustments as understanding is gained. Careful monitoring of each management experiment is needed to ensure that managers are accountable for management actions, and to learn what works and what does not work. Feedback must result from monitoring, so that management experiments are refined, viable management alternatives are discovered and recorded, and poor methods are discarded. To be successful with this approach, selected management methods should all have the characteristic of conserving options rather than losing them. Giving up options is like giving up capital in the financial world. Management decisions are often needed before all of the relevant information or guidance is available. A resource management model that is adaptive and based on conserving options allows both speculative actions and future adjustments to those actions where they are wrong or not favored.

FUTURE RESEARCH NEEDS

Future research on forest insects and pathogens in eastern Oregon and Washington should address three primary topics: insect and pathogen population dynamics in unmanaged and managed forests; ecological roles and effects of insects and pathogens; and, effects of natural disturbances and forest management practices on insects and pathogens, and their natural enemies.

Insect and pathogen population dynamics in unmanaged and managed forests—Forest insects and pathogens are important disturbance agents affecting ecosystem health in both favorable and unfavorable ways. The ecology and roles of their natural enemies, and other regulatory processes, are equally important. Critical gaps exist in the knowledge of insect and pathogen population dynamics, regulatory processes and organisms, interactions, roles, and effects. Important research questions are:

- ☐ What are the population dynamics of insects and pathogens in each major climax forest series in eastern Oregon and Washington?
- ☐ What are the important natural enemies, what are their habitat requirements, and what are their associations and responses to changing environments?
- ☐ Can hazard-rating systems be developed for plant associations and successional communities, to predict insect and pathogen responses to natural and management disturbances.

Ecological roles and effects of insects and pathogens—Dwarf mistletoe infection results in substantial economic loss in nearly all coniferous species in eastern Oregon and Washington. On the other hand, mistletoe-infected branches provide nesting and roosting habitat for at least three kinds of owls, and hiding cover for other birds and mammals. Stem decays cause severe economic losses, but decayed trees provide ideal nesting and hiding habitat for numerous birds and mammals. Root diseases cause widespread mortality in several coniferous species, and predispose trees to further bark beetle attack. Root diseases and bark beetles are also a major cause of canopy gaps and may be important to forest succession, wildlife habitat, and nutrient cycling. The same comparisons are appropriate for major conifer defoliators. Important research questions are:

- ☐ What are the roles of root pathogens, bark beetles, and defoliators in forest succession, wildlife habitat development, and nutrient cycling in the major plant associations of eastern Oregon and Washington?
- ☐ What are the roles of stem decay fungi and dwarf mistletoes in creating nesting and roosting habitat for birds and mammals?
- ☐ Can replacement wildlife habitats be developed using these organisms in areas that are now depauperate as a result of past management practices.

Effects of natural disturbances and forest management practices on insects and pathogens and their natural enemies—Fire, drought, and other severe climatic disturbances have shaped forests of eastern Oregon and Washington for millennia. Knowledge about how these disturbances affect vegetation, insect and pathogen populations and their natural enemies is extremely limited. Important research questions are:

- ☐ What effects do fire, drought, and severe weather disturbances have on insect and pathogen population dynamics in each major climax forest series?
- ☐ How do these disturbances affect natural enemies of insects and pathogens?
- ☐ In each major climax forest series, what are the effects of various vegetation management practices on insect and pathogen populations and their natural enemies?
- ☐ Can conventional or new ecosystem management techniques minimize adverse affects, and maintain or enhance beneficial effects and roles of pathogens and insects and their natural enemies? Are other management techniques, or variants of currents techniques more suitable?

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Appendix A—List of common and scientific names - TREES

Common Name	Scientific Name
Balsam fir	<i>Abies balsamea</i> (L.) Mill.
Douglas-fir	<i>Pseudotsuga menziesii</i> (Mirb.) Franco
Engelmann spruce	<i>Picea engelmannii</i> Parry ex Engelm.
Grand fir	<i>Abies grandis</i> (Dougl. ex D. Don) Lindl.
Lodgepole pine	<i>Pinus contorta</i> var. <i>latifolia</i> Dougl. ex Loud.
Mountain hemlock	<i>Tsuga mertensiana</i> (Bong.) Carr.
Noble fir	<i>Abies procera</i> Rehd.
Oregon white oak	<i>Quercus garryana</i> Dougl. ex Hook.
Pacific silver fir	<i>Abies amabilis</i> Dougl. ex Forbes
Ponderosa pine	<i>Pinus ponderosa</i> Dougl. ex Laws.
Shasta red fir	<i>Abies magnifica</i> A. Murr.
Subalpine fir	<i>Abies lasiocarpa</i> (Hook.) Nutt.
Western hemlock	<i>Tsuga heterophylla</i> (Raf.) Sarg.
Western juniper	<i>Juniperus occidentalis</i> Hook.
Western larch	<i>Larix occidentalis</i> Nutt.
Western redcedar	<i>Thuja plicata</i> Donn ex D. Don
Western white pine	<i>Pinus monticola</i> Dougl. ex D. Don
White fir	<i>Abies concolor</i> (Gord. & Glend.) Lindl. ex Hildebr.

Appendix A (continued)—List of common and scientific names, INSECTS

Common Name	Scientific Name
Balsam woolly adelgid	<i>Adelges piceae</i> (Ratzeburg)
Douglas-fir beetle	<i>Dendroctonus pseudotsugae</i> Hopkins
Douglas-fir engraver beetle	<i>Scolytus unispinosus</i> LeConte
Douglas-fir tussock moth	<i>Orgyia pseudotsugata</i> (McDunnough)
Fir engraver	<i>Scolytus ventralis</i> LeConte
Fir root beetle	<i>Pseudohylesinus granulatus</i> (LeConte)
Larch casebearer	<i>Coleophora laricella</i> (Hübner)
Lodgepole needle miner	<i>Coleotechnites milleri</i> (Busck)
Mountain pine beetle	<i>Dendroctonus ponderosae</i> Hopkins
Pandora moth	<i>Coloradia pandora</i> Blake
Pine butterfly	<i>Neophasia menapia</i> (Felder and Felder)
Silver fir beetle	<i>Pseudohylesinus sericeus</i> (Mannerheim)
Spruce beetle	<i>Dendroctonus rufipennis</i> (Kirby)
Sugar pine tortrix	<i>Choristoneura lambertiana</i> (Busck)
Western balsam bark beetle	<i>Dryocoetes confusus</i> Swaine
Western pine beetle	<i>Dendroctonus brevicomis</i> LeConte
Western pine shoot borer	<i>Eucosma sonoma</i> Kearfott
Western spruce budworm	<i>Choristoneura occidentalis</i> Freeman

Appendix A (continued)—List of common and scientific names, DISEASES

Common Name	Scientific Name
Annosum root disease	<i>Heterobasidion annosum</i> (Fr.) Bref.
Armillaria root disease	<i>Armillaria ostoyae</i> (Romag.) Herink
Brown cubical butt rot	<i>Phaeolus schweinitzii</i> (Fr.) Pat.
Comandra rust	<i>Cronartium comandrae</i> Pk.
Douglas-fir dwarf mistletoe	<i>Arceuthobium douglasii</i> Engelm.
Elytroderma needle disease	<i>Elytroderma deformans</i> (Weir) Darker
Indian paint fungus	<i>Echinodontium tinctorium</i> E. & E.
Laminated root rot	<i>Phellinus weirii</i> (Murr.) Gilb.
Lodgepole pine dwarf mistletoe	<i>Arceuthobium americanum</i> Nutt. ex Engelm.
Stalactiform rust	<i>Cronartium coleosporoides</i> Arth. f. <i>coleosporoides</i>
Tomentosus root disease	<i>Inonotus tomentosus</i> (Fr.) Teng.
True fir dwarf mistletoe	<i>Arceuthobium abietinum</i> Engelm. ex Munz f.sp. <i>concoloris</i> Hawksworth and Wiens
Western dwarf mistletoe	<i>Arceuthobium campylopodum</i> Engelm.
Western hemlock dwarf mistletoe	<i>Arceuthobium tsugense</i> (Rosendahl) G.N. Jones
Western larch dwarf mistletoe	<i>Arceuthobium laricis</i> (Piper) St. John
White pine blister rust	<i>Cronartium ribicola</i> Fisch.

Effects of Long-Term Grazing by Big Game
and Livestock in the Blue Mountains
Forest Ecosystems

by

Larry L. Irwin, John G. Cook, Robert A. Riggs,
and Jon M. Skovlin

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INTRODUCTION

Management programs developed to restore and sustain forest health must use socially and economically acceptable methods. Assessing past management practices can help identify acceptable options for overcoming current forest health problems. Here, we assess the effects of long-term grazing by livestock and big game animals on forest ecosystem processes. Such assessment is appropriate because long-term herbivory by large mammals may either reduce or increase ecosystem productivity (Crawley 1983, Gessaman and MacMahon 1984), including that of forests (Pastor and others 1988).

We conduct this assessment from the view that large-scale systematic disturbances, primarily logging and fire suppression, have profoundly influenced vegetation patterns and vegetation-herbivore interactions. We emphasize the Blue Mountains of northeastern Oregon and southeastern Washington because of the 130-year history of livestock use in an area rich in big game animals. We assume that results from the Blue Mountains represent, to various degrees, other forests in the interior Northwest. We emphasize cattle and elk (see appendix A for scientific names) because they are numerous and widespread and because long-term information is available on both species and their habitats. We also emphasize plant-soil-animal interactions, including nutrient cycling and feedback mechanisms that influence animal population performance. These topics are relevant to both economic development and an understanding of ecological processes.

First, we describe ecosystems important to large herbivores, and summarize management histories and trends among elk and livestock populations in the Blue Mountains. Next, we review published scientific literature that provides a basis for predicting the effects of cattle and elk on forested ecosystems. Then, we review local studies to determine the accuracy of predictions from the literature. Finally, we use the results to suggest management options that might be tested by adaptive management experiments (Walters 1986) within a comprehensive program for restoring forest health.

IMPORTANT ECOSYSTEMS FOR LARGE HERBIVORES IN THE BLUE MOUNTAINS

Assessing herbivory begins with describing the major ecosystems that are grazed. Küchler (1964) described 10 ecosystems for the Blue Mountains, based on their potential vegetation. Garrison and others (1977) described 11 ecosystems that were generally similar to those in Küchler (1964); they distinguished mountain meadow ecosystems and excluded Küchler's grand fir-Douglas-fir class. Thomas and others (1979) described 15 ecosystems important to wildlife in the Blue Mountains.

Franklin and Dyrness (1973) described eight major forest and woodland vegetation zones and several steppe and shrub-steppe associations for the Blue Mountains. They paid particular attention to successional variation in subalpine grasslands, mountain meadows, and riparian communities. Other workers subdivided the major ecosystems into vegetation communities and associations (Hall 1973, Johnson 1959, Johnson and Clausnitzer 1992, Johnson and Simon 1987).

The most important ecosystems for large herbivores in the Blue Mountains are those at mid-elevations. These primarily include open plant communities in ponderosa pine and Douglas-fir zones, and mixed conifer communities at higher elevations. Large herbivores often graze early seral stages heavily after timber harvesting in the mixed conifer zone (Skovlin and others 1989), and they also graze in timber stands. Steppe and shrub-steppe zones at lower elevations and high mountain and subalpine zones at higher elevations also contain plant communities of great importance to large herbivores. The low-elevation zones include grasslands, sagebrush, and juniper woodlands in association with foothills and

canyons (Driscoll 1962). These zones are particularly important as spring, fall, and winter range for all classes of ungulates (Sheehy 1987). The high-elevation montane grassland types, which are mixed with forest communities, provide important summer range (Reid 1941).

Mountain meadow communities are interspersed throughout the Blue Mountains, where streams have low gradients and wide flood plains. These communities are important to large herbivores because they produce significant amounts of nutritious forage in late summer and fall (Holechek and others 1982). Mountain meadows comprise not more than one percent of the total summer range for livestock and big game, yet produce up to 15 times more forage than surrounding rangelands (Pickford and Reid 1942a).

MANAGEMENT HISTORY OF LARGE MAMMALS IN THE BLUE MOUNTAINS

Livestock History and Federal Management Practices: 1850-Present

Little historical information about livestock is available before European settlement, although the local Cayuse and Nez Perce Indians kept horses as early as 1730 (Haines 1938). The first extensive exploitation of the forested grasslands occurred between 1843 and 1870, when thousands of cattle were herded over the Oregon Trail (Evans 1991). Journals of early pioneers described large yellow pine forests with grassy glades that looked like fields of grain, and told of a landscape that burned so often no underbrush was left (Wickman and others 1993).

Settlers' livestock primarily used forage along travel routes as they crossed the Blue Mountains to the Willamette Valley in the western Oregon Territory. That pattern changed when eastern Oregon was settled, after western valleys became populated. By 1860, small cattle herds were scattered from Walla Walla, Washington, to Farewell Bend on the Snake River upstream from Hells Canyon (Oliphant 1932). Subsequently, tens of thousands of cattle and nearly as many horses from the Willamette Valley were brought to the area after gold strikes in Canyon City and Auburn, Oregon (Oliphant 1968).

Stockmen moved their animals to the foothills and to more remote regions as homesteaders began tilling what had been cattle winter range in fertile valleys. This gradual expansion of livestock use continued into the early 1870s. Livestock numbers increased eight- to ten-fold from the 1870s through the 1880s, reflecting an influx of transient cattle that were herded from western Oregon to the Great Plains from 1875 to 1885 (Oliphant 1964).

We show (fig. 1) trends in numbers of livestock from 1860 to 1960 in nine Blue Mountains counties (four in Washington and five in Oregon). Compiled from the U.S. Census, Bureau of Statistics (U.S. Department of Commerce 1900) and from the Census of Agriculture Area Reports for Oregon and Washington (State of Oregon 1890), the information reflects the total animal units present in the nine-county area but does not accurately indicate the proportions of those animals that grazed in the present-day National Forests.

Evidence of changes in range vegetation in the ecoregion that includes the Blue Mountains was recognized as early as the 1870s. In a supplement to the 1880 census (Gordon and others 1883), a group of livestock producers reported:

... we find generally in Washington territory and in Oregon that free range pasturage, originally strong and luxuriant, has been injured by overstocking. The pasturage is generally good, except the timbered mountain heights in the northwest, ..., and along the whole extent of the Cheyenne trail for a couple of miles in breadth.

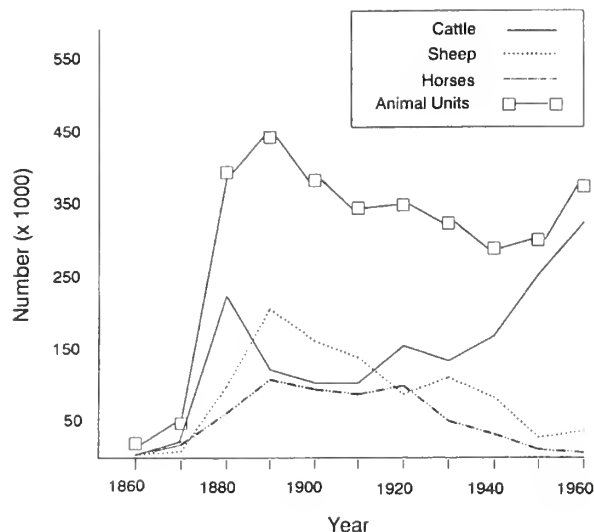


Figure 1. Trends in livestock numbers in the Blue Mountains of northeastern Oregon and southeastern Washington, 1860-1960. Information for this chart was compiled from the U.S. Census Bureau of Statistics, U.S. Department of Commerce, and from the Census of Agriculture Area Reports for Oregon and Washington, Washington, DC: U.S. Government Printing Office.

Gordon and others (1883) believed that forested rangelands were stocked at perhaps four times their sustainable capacity by 1880, and they had been subjected to such intensive grazing for the previous 10 to 15 years. Gordon and others (1883) wrote that eastern Oregon grazing land, "Probably,..., will not now support more than one-third of the cattle that it fattened five or seven years ago." Domestic sheep continued to increase, however, a result of high prices for wool. Sheep production peaked in the 1890s (fig. 1), and numbers of cattle and horses stabilized or declined. Total animal numbers were at an all time high of almost 450,000 animal unit equivalents (an animal unit equates five sheep with one horse or cow).

Consequences of continued high stocking rates included loss of stable vegetation cover, which resulted in erosion on steep slopes (Forsling 1931). Tree reproduction was browsed and trampled along stock routes and in key foraging areas. Exposed mineral soil led to establishment of tree seedlings (Rummel 1951). Grazing removed vegetation that, when dry, became fine fuels. Thus, grazing in the ponderosa pine¹ zone altered the conditions under which ground fires previously controlled establishment of dense stands of pine seedlings (Hall 1977). In doing so, grazing probably contributed to changes in fire frequency in the ponderosa pine zone. Intensive grazing also led to establishment of alien, often noxious, plants (Branson 1985).

Although the apparent range destruction alarmed government officials and stockgrowers, large livestock herds continued to graze public lands until the Forest Reserves were established. The Forest Reserve Act of March 1, 1895, created the Forest Reserves specifically to protect water and produce trees.

The National Academy of Sciences (1898) focused national attention on unregulated grazing in the Forest Reserves in a report to the Secretary of the Interior. That report alleged that mass destruction of natural resources had occurred, particularly by transient sheep. Sheep grazing was banned, except in Oregon and Washington, where studies had shown sheep grazing was not detrimental (Coville 1898). Enforcement was difficult at best, however, and livestock trespassed widely on mountain summer ranges. Range wars erupted as sheep and cattle producers feuded over limited forage resources (Griffiths 1903).

The creation of the U.S. Department of Agriculture Forest Service in 1906 helped to enforce regulations and eliminate trespass. Although grazing was not mentioned as an allowable practice in Forest Reserve legislation, the Secretary of Agriculture instructed the Chief Forester (U.S. Department of Agriculture

1905) to, "...see to it that the wood, water, and forage of the reserves are conserved and wisely used." Rules and regulations for livestock grazing on Forest Reserves were specified shortly thereafter. Forest Service personnel and stockgrowers negotiated agreements on range division by class of livestock, permit application procedures, periods of use, grazing fees, dates of allowable grazing, and commensurability (Tucker 1940). Commensurability meant that property of a participating ranch had to have the capacity to provide adequate forage for livestock when they were not grazing on Federal allotments.

Management for productive herds required accurate estimates of the numbers of animals on the range. The first reliable record of livestock grazing for the Wallowa Reserve was in 1911 (Tucker 1968). Previous boundary changes, allotment consolidations and inability to stop animal trespass reduced the accuracy of counts. Trespassing animals probably accounted for 25 percent or more of the use on this reserve (Tucker 1968).

Attempts to balance forage supply with livestock demand resulted in a 70 percent decline in livestock use on the Wallowa and Whitman Reserves (now the Wallowa-Whitman National Forest) from 1911 to 1970 (fig. 2). Most of that decline was due to reductions in sheep (table 1).

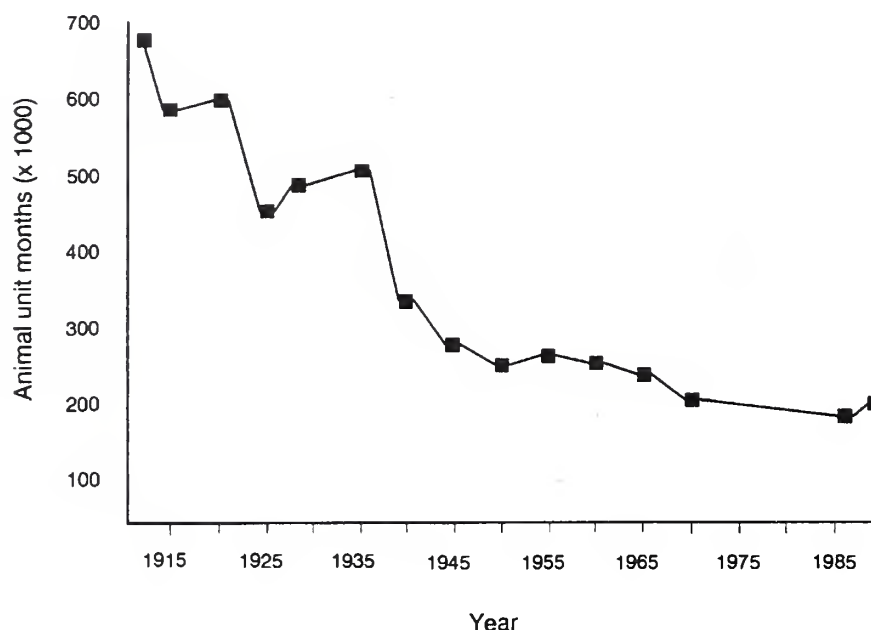


Figure 2. Trends in livestock use on the Wallow-Whitman National Forest, 1911-90.

Table 1—Numbers of cattle and domestic sheep grazing on the Wallowa Reserve, Oregon, 1911-1961 (from Tucker 1968)

Year	Cattle	Sheep
1911	13,625	121,740
1921	23,830	67,203
1931	9,654	71,213
1941	8,121	41,764
1951	9,780	15,276
1961	11,255	16,447

Federal agencies needed improved technical information for managing range lands under the new regulations. Sampson (1914) investigated plant succession on depleted subalpine fir forested grasslands on the Standley sheep allotment on the Wallowa National Forest in 1907. Sampson (1913) recommended varying the period of use of ranges, and he experimented with domestic grass seedings to restore the productivity of the range (Sampson 1908). Methods of open range sheep production were compared with conventional herding systems. Open range production, which means that sheep were not tended by herders with dogs that returned sheep to a camp or corral each evening, appeared to be economical only if predators were eliminated (Jardine 1910). Also, Fleming (1910) investigated the influence of livestock grazing on tree regeneration on the Malheur National Forest.

Steffens (1915) conducted a range reconnaissance survey in 1914 to locate and map the distribution of forage supplies. He found cheatgrass, an introduced annual grass, on only six areas within portions of 12 square miles (sections) on the former Imnaha Reserve and adjacent private lands (memo to files from Melvin H. Burke, Assistant Range Examiner, Wallowa National Forest, November 19, 1938). Cheatgrass presently occurs on nearly every section below about 3000 ft elevation.

Livestock numbers increased slightly on Forest allotments after World War I, reflecting a policy change to increase food production. New policies eased restrictions on livestock numbers and season of use to such an extent that abusive grazing practices occurred. A report to Congress in 1935 revealed some degree of forage depletion on most of the forested mountain summer ranges (U.S. Senate 1936). The areas and amount of depletion (fig. 3) were based on departure from what was assumed to have existed in the absence of livestock grazing. Livestock use on National Forests in the Blue Mountains, as represented by trends on the Wallowa-Whitman National Forest, has remained relatively stable in recent years (fig. 2).

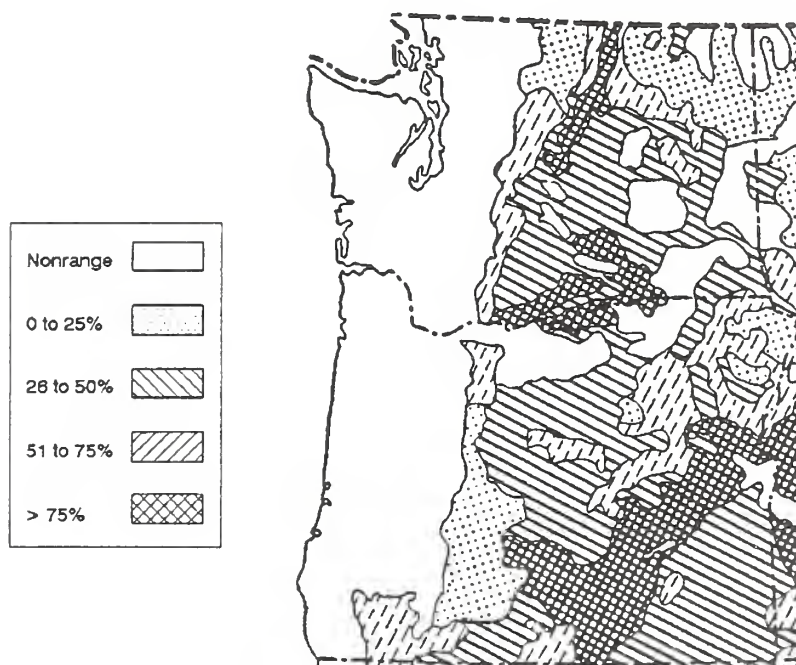


Figure 3. Extent of forage depletion on ranges of eastern Oregon and Washington, 1935 (Senate Document 199, *The Western Ranges*).

Research since the 1940s provided managers with a scientific basis for range management. More than 75 publications dealing with ungulate grazing on forested rangelands resulted from studies on the Starkey Experimental Forest and Range (Skovlin 1991). Methods for monitoring and judging changes in range

condition or range succession have come into standard use (for example, Pickford and Reid 1942b, 1946, Reid and Pickford 1946), although they are difficult to interpret on grazed forested sites because of relatively rapid succession. Studies on grazing capacities and rangeland sustainability determined proper grazing intensity on key forage plants (for example, Pickford and Reid 1948). The recommendation has continually been revised downward, based on longer, more highly controlled studies (Strickler 1969).

Studies conducted in subalpine areas show that summering elk and sheep can exceed the allowable use on several grasses and grasslike plants (Pickford and Reid 1943). These authors also provided a model for judging subalpine range condition based on plant composition and production (Pickford and Reid 1942a). That model continues to guide determinations of the long-term sustainability of grazed subalpine rangelands in the Blue Mountains.

Research and management efforts helped restore productivity to abused rangelands, and recovery of some areas over the past 50 years has been striking. Improvements on one allotment, the Tenderfoot Basin allotment, have been chronicled since the late 1950s (Reid and others 1980, Reid and others 1991, Strickler 1961). Sheep continue to graze this allotment irregularly, with evidence of continued recovery. Mule deer and elk, in particular, have increased use of this allotment.

Range condition on the Standley sheep allotment in the Minam River drainage has been monitored since 1908 (Sampson 1909, Strickler and Hall 1980). Sheep numbers on this allotment declined by over 90 percent from those at the turn of the century, and sheep have not used this allotment regularly since 1980. Recovery is evident, although some sites contain vegetation in early stages of secondary succession.

Range research since the middle of this century has centered on determining proper seasons of livestock use, grazing systems, and stocking for various ecosystems (Skovlin and others 1976). In 1950, fewer than one in five National Forest cattle allotments in eastern Oregon and Washington was managed by systems other than season-long grazing. By 1970, more than three of five allotments were at least managed under a deferred rotation system (A. Denham, pers. comm.).

The Wallowa-Whitman National Forest (1980a, b, c, d; 1981) evaluated condition and trends in grazing allotments within five Oregon Department of Fish and Wildlife (ODFW) Wildlife Management Units (fig. 4). These subjective evaluations suggest that ranges in allotments in the Starkey and Minam Units were generally in satisfactory condition. Information was lacking from allotments in the Imnaha Unit, and many allotments within the Snake River and Chesnimnus Units were judged in unsatisfactory and declining condition. The poor conditions in the Snake and Chesnimnus Units were believed to be a result of poor livestock management practices before the Forest was established. The subjective evaluations for the Snake and Chesnimnus allotments also suggested that combined use by big game and livestock was at or above the ability of the range to sustain productivity.

Recent concerns for aquatic and terrestrial wildlife, water quality, and fisheries led to studies on the proper grazing intensities in riparian and wetland habitats (for example, Kauffman 1982, Kauffman and others 1982, Skovlin and others 1977, Skovlin 1984). Current research at the Starkey Experimental Forest and Range features habitat use and forage resource partitioning among cattle, deer, and elk (Johnson and others 1991). Relatively little research has evaluated dynamics of managed forest sites that are grazed.

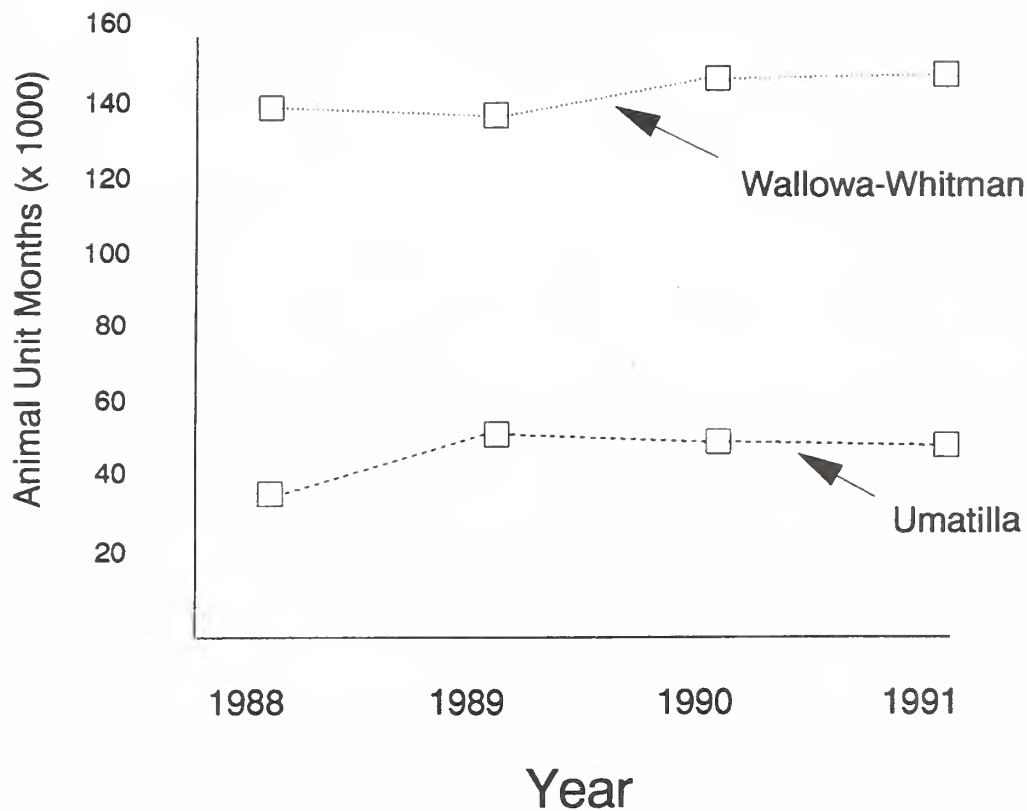


Figure 4. Trends in livestock grazing allotments on the Umatilla and Wallowa-Whitman National Forest, 1988-91.

History and Management of Elk in the Blue Mountains

The archeological record indicates that elk have been present in the Columbia Basin and probably adjacent forest zones for at least the last 10,000 years (McCorquodale 1985). They were relatively common after 1840, when settlers traveled the Oregon Trail (Bailey 1936, Shay 1954, Thwaites 1905). Elk were an important subsistence resource for Native Americans prehistorically (McCorquodale 1985) and for the early Euro-American settlers (ODFW 1992). Unregulated subsistence and market hunting, however, which coincided with initial livestock grazing and land cultivation, nearly extirpated elk from the Blue Mountains by the late 1880s. The State government and private groups responded by banning both elk hunting and the selling of elk meat, and by translocating elk from other areas (table 2).

Table 2—History and management of Rocky Mountain elk in northeast Oregon and southeast Washington

Date	Comments¹
Early 1800s	Elk not present in abundance (historical accounts).
Late 1800s	Market hunting resulted in elk scarcity (3, 4, 5, 7, 8).
1899	Oregon legislature prohibits selling elk meat, apparently resulting in a 10-year ban on hunting (3, 4, 8).
1905	Hunting briefly re-opened in eastern Oregon (3, 4, 8).
1909-1932	Hunting seasons closed; elk populations increased. (3, 4, 5, 8).
1912	Twenty-two elk from Jackson, WY, released in Wallowa County, OR (1, 2, 4, 8).
1913	Twenty-nine elk from Yellowstone National Park (YNP) released, Pomeroy, WA (2, 6, 9).
1913	Twenty-five elk from YNP released near Walla Walla, WA (2, 6).
1916	Seven hundred and ten elk estimated to occur in Baker, Umatilla, Union and Wallowa Counties, OR (1, 10).
1918	Fifty YNP elk released near Walla Walla, WA (2).
1924	Complaints about competition between elk and livestock begin (3).
1926	Elk population for Blue Mountains at 3,663 (1).
1926	Elk population for Wallowa County, OR, estimated at 669 (1).
1927	Hunting season first opens for elk in southeastern Washington (2, 9).
1931	Thirty YNP elk released near Dayton, WA (2, 9).
1932	Estimated 3,000 elk in Wallowa County (2).
1933	Estimated 11,030 elk in Oregon (1).
1933	Hunting re-instituted in Oregon; 23-25 October for 2-point or larger bulls; parts of Baker, Wallowa, Union, Umatilla Counties; 579 elk killed (3, 4, 5, 7).
1934-37	Ten-day mid-November season in Oregon; 550-750 antlered bulls killed (3, 8).
1937	Six hundred and twenty elk reported through Whitman National Forest check stations (5, 8).
1939	First antlerless season; 379 females killed (3).
1940	Between 50-150 elk harvested in southeastern Washington since 1927 (9).
1941	General either-sex hunts, Oregon; unrestricted hunters; 3,741 elk killed (9).
1949	A total of 26,000 hunters in Oregon killed 8,685 elk, including 6,071 antlerless elk (3).

Table 2—History and management of Rocky Mountain elk in northeast Oregon and southeast Washington (continued)

Date	Comments
1955-1963	Hunters and elk harvest continue to increase. (3)
1964	Separate tags required for eastern and western Oregon; extensive intrastate translocations of elk into the 1970s (3).
1970s	Elk populations increased by 45% during the decade; bull ratios declined; 19-day season, last 5 days of which included antlerless; > 65,000 hunters (3).
1972	Declining bull ratios led to limited-entry permits for bulls; 3,295 permits for antlerless elk, increasing to 10,675 by 1978. (3)
1979-1985	Split hunting seasons to disperse hunting pressure; bull ratios improve by 25%; small increase in populations; 16,000 Rocky Mountain elk killed; antlerless tag numbers nearly double; > 75,000 hunters (3).
1981	Oregon adopts management objectives for elk density and cow-calf ratios (3).
Post 1985	Concern for increased road access, reduced cover and bull escapement. Hunter numbers declined to > 70,000 (3).

¹Numbers in parenthesis refer to the following references:

1. Bailey, V. 1936. The mammals and life zones of Oregon. North American Fauna, No. 55, Washington, DC: U.S. Department of Agriculture, Bureau of Biological Survey. 416 p.
2. Couch, L.K. 1953. Chronological data on elk introductions in Oregon and Washington. Murrelet 16:3-6.
3. Edwards, D. 1992. Draft elk management plan. Portland, OR: Oregon Department of Fish and Wildlife. 79 p.
4. Gildemeister, J. 1992. Bull trout, walking grouse and buffalo bones-oral histories of northeast Oregon fish and wildlife. La Grande, OR: Oregon Department of Fish and Wildlife. 64 p.
5. Huff, R. 1953. Early day game conditions. Memo to files, Jan. 19, 1953, Regional Office, W-Supervision-General. Baker City, OR: On file at Supervisor's Office, Wallowa-Whitman National Forest, 9 p.
6. Robbins, R.L.; Redfearn, D.E.; Stone, C.P. 1982. Refuges and elk management. Pages 479-507. In: Thomas, J.W; Towell, D.E., eds. Elk of North America: ecology and management. Harrisburg, PA: Stackpole Books. 479-507.
7. Skovlin, J.M. 1991. Fifty years of research progress: a historical document on the Starkey Experimental Forest and Range. Gen. Tech. Rep. PNW-GTR-266. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 58 p.
8. Shay, R. 1954. Immigrant elk: the story of two early-day elk transplants to Wallowa and Clackamas counties. Oregon State Game Commission Bulletin. 1954:3-8.
9. Tucker, G.J. 1940. History of the northern Blue Mountains. On file with: Pomeroy Ranger District, Umatilla National Forest, Pendleton, OR. 169 p.
10. Tucker, G.J. 1968. History of the Wallowa National Forest. 3 volume unpublished document. On file with: Supervisor's Office, Wallowa-Whitman National Forest, P.O. Box 907, Baker City, OR. 97814.

The earliest official elk census in the Blue Mountains was apparently made in 1916, when the total population for Baker, Umatilla, Union, and Wallowa counties was estimated at 710 animals (Bailey 1936; Tucker, n.d.). The next recorded census was in 1926, when the population for Wallowa County was estimated at 669 and that for the entire Blue Mountains was 3663 (Bailey 1936). Some of the animals used in deriving the 1916 estimate may have been survivors or offspring from translocations of elk from Yellowstone Park to Pomeroy and Walla Walla, Washington (table 2). Likewise, the 1926 estimate in Wallowa County explicitly included both native animals and the survivors and offspring from earlier transplants, according to Shay (1954). The total elk population in the Blue Mountains probably did not contain more than a few thousand animals in the 1920s.

More recent records paint a vastly different picture. In the 20 population management units in northeastern Oregon (fig. 4), which roughly correspond to the four counties in the population estimates of 1916 and 1926, ODFW estimated the aggregate winter population in 1980 at 58,500 animals. Therefore, the residual and translocated elk herds grew into one of the largest regional populations in North America. Below, we review the management practices that fostered such growth.

In Oregon, elk management generally has consisted of several decades of no legal hunting followed by years of conservative legal harvests to facilitate population growth (table 2). Management from 1889 through 1932 focused on increasing herd size. No hunting was allowed during this time, except for a short period between 1905 and 1909. Bull-only hunting was reauthorized in 1933. Legal harvest of females was reauthorized in 1939, so the female segment of the regional population probably grew relatively unchecked for 30 years. General either-sex hunting prevailed for the next 30 years. In the early 1970s, concern for overharvest led to the first limited-entry hunts. The development of split seasons followed in 1979 in an effort to accommodate increasing numbers of hunters.

Surveys were initiated shortly after World War II to monitor elk populations. Survey procedures were standardized by 1953 to estimate density of animals on winter range (in terms of elk sighted per mile of survey route) and winter ratios of bulls to cows to calves on selected herd ranges. Monitoring was gradually expanded to other areas; in 1960, the system of population management units (fig. 4) was established. Population surveys were conducted from vehicles and horseback until 1960. Some surveys were conducted by using fixed-wing aircraft in the early 1960s; by 1965, aircraft were used in all management units. Management objectives for winter density and bull:cow:calf ratios were adopted by the Oregon Fish and Wildlife Commission in 1981, and ceilings were set on the size of some populations (ODFW 1982). Estimates for winter densities since 1953 (fig. 5) showed pronounced increases for most populations, particularly prior to the 1980s.

Recent management on behalf of elk populations has expanded to include habitats. Recommendations for winter and summer thermal cover have been adopted by the National Forests to enhance elk distribution and use of landscapes (Thomas and others 1979, Thomas and others 1988b), and to reduce harassment from recreationists (Skovlin 1982). Concern also has grown for the vulnerability of elk to hunting in managed landscapes, mostly focused on increased access to hunters as road densities increased and hiding cover was reduced by timber harvests (Christensen and others 1991). High numbers of elk hunters also have been implicated (Vales and others 1991).

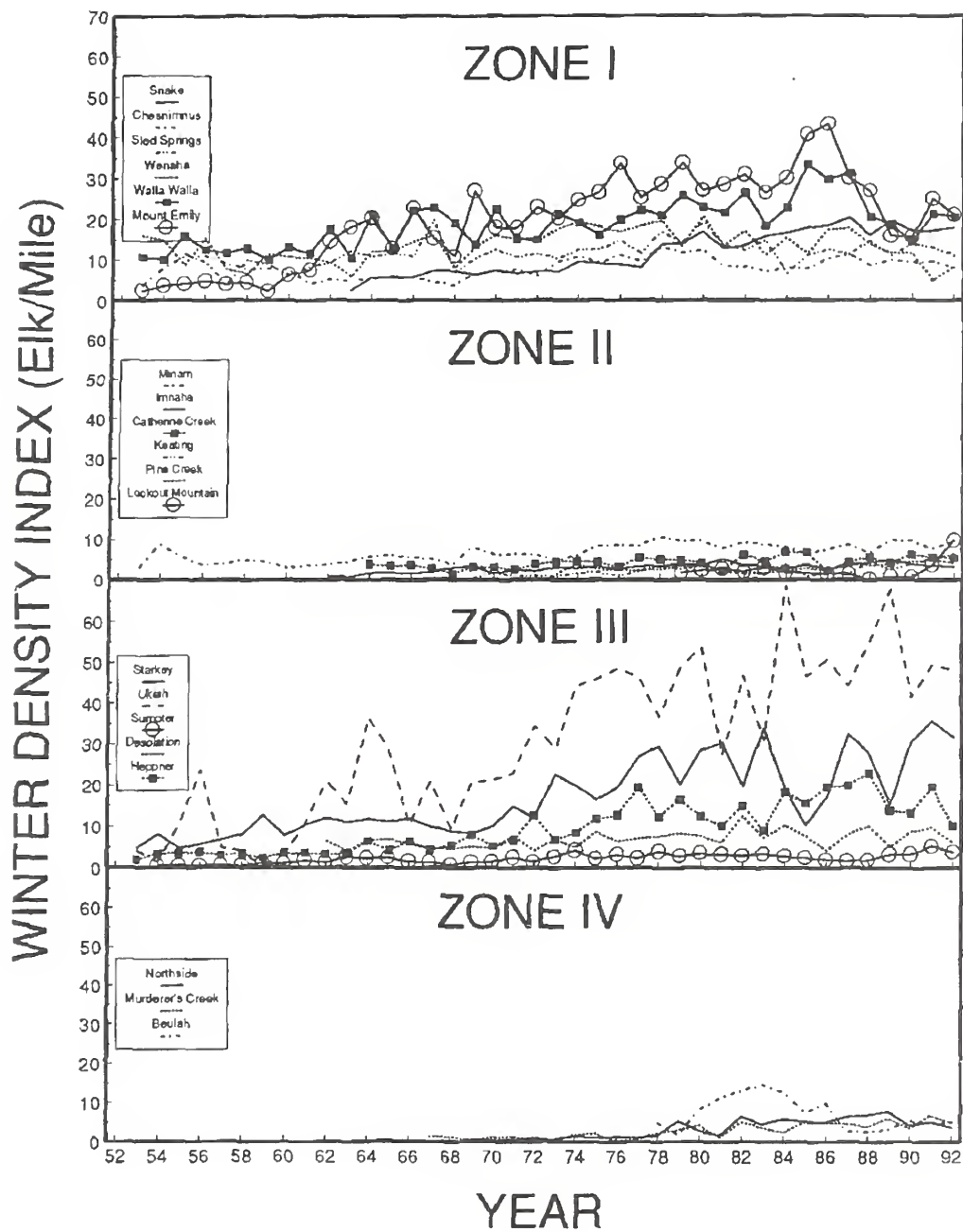


Figure 5. Recorded annual density indices, by zone and unit, in the northeastern management area of Oregon, 1953-92. Pre-1960 data were derived by summing data for herd range samples nested within the current Game Management Units. Source: Oregon Department of Wildlife annual reports, 1953-92.

RELATIONS OF LARGE HERBIVORES TO ECOSYSTEM PROCESSES

Large herbivores influence ecosystem processes beyond reducing the standing crop of vegetation, compacting soil, or removing preferred forage species from plant communities (Crawley 1983, Gessaman and MacMahon 1984). Soil-plant-herbivore systems are highly interactive, with massive feedback between the dynamics of both the vegetation communities and the herbivore populations. Herbivory by large African ungulates strongly influences such ecosystem processes as energy flow, nutrient cycling, and the frequency and extent of wildfires (McNaughton and others 1988). Such soil-plant-animal systems cannot be understood without close consideration of the large mammals (Naiman 1988), and population dynamics of the large mammals cannot be understood without considering them in an ecosystem context (fig. 6).

Interactions between large herbivore populations and their environments are summarized in the concept of carrying capacity. Caughley (1979) defined two types of carrying capacity: economic and ecological. Economic carrying capacity is the density of animals, held constant by harvesting, that provides maximum sustained yield, as measured in weight of animals or net revenue. Ecological carrying capacity is the density of ungulates that could be sustained if they were not harvested. Carrying capacity can also be expressed as a characteristic composition and density of vegetation.

Vegetation production and composition and animal densities fluctuate (Caughley 1977) in the process of interacting with each other and weather. This natural process limits the range of alternative populations that can be maintained via hunting or other harvesting (Caughley 1979). Range managers seek to maximize revenues by maintaining livestock densities at economic carrying capacity. Such management accepts little or no change in vegetation composition, and annual vegetation production fluctuates primarily with precipitation. Range managers typically classify animal densities that are above economic carrying capacity as overpopulations (Caughley 1979).

Populations of wild ungulates that are hunted may be maintained below, equal to, or above economic carrying capacity. Populations that are not hunted, such as wild ungulates living entirely in National Parks are expected to exist at densities near ecological carrying capacity (Houston 1982). As populations increase toward ecological carrying capacity, vegetation production may decline, and composition may be modified (Houston 1982). Composition of plant communities may be affected by low ungulate densities as well, through selective foraging.

Below, we summarize literature on soil-plant-animal relations and develop predictions for the Blue Mountains Ecoregion. We reiterate that these relations are complex because both wild and domestic ungulates are harvested, and fire control and previous logging have modified vegetation communities. Such large-scale disturbances create new dynamic equilibria between herbivores and vegetation.

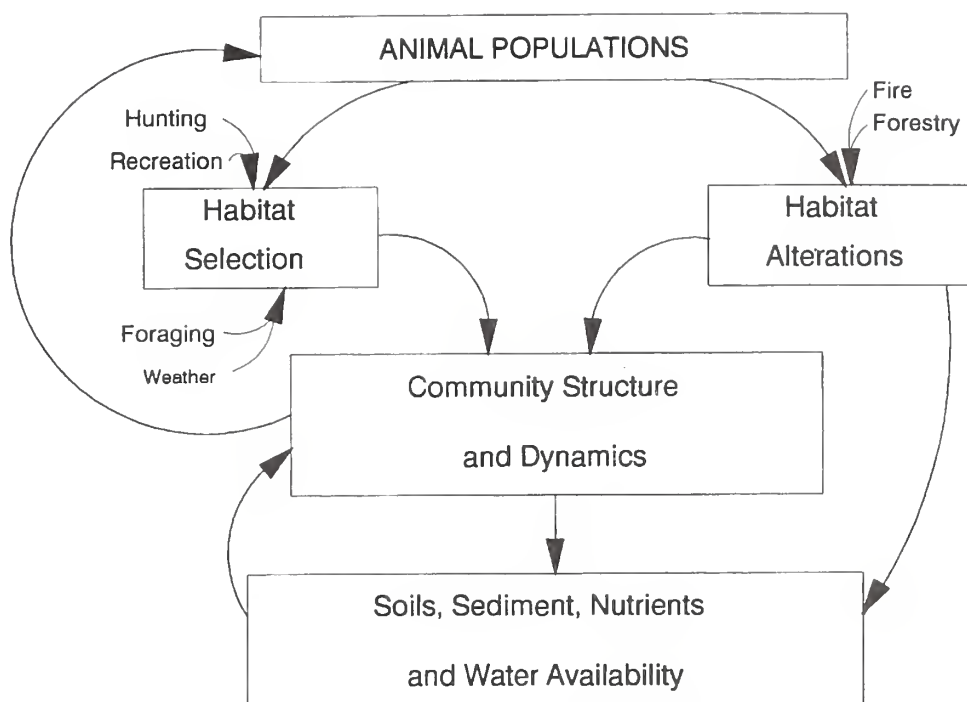


Figure 6. Herbivores influence ecosystem dynamics by their foraging and by physical habitat alterations. These effects are transmitted to the community, resulting in long-term changes to biogeochemical cycles (after Naiman 1988).

Predicted Effects of Large Herbivores on Plants and Soils in Forests

The effects of livestock and big game herbivory on forest stands have received little attention by National Forests, despite graphic examples of substantial effects in some areas (for example, Rasmussen 1941, Pastor and others 1988). Pastor and others (1988) documented significant effects to forest ecosystem processes from browsing by moose on Isle Royale, Michigan. Exclosures, or fenced plots where moose were not allowed to browse, have been maintained on the island for over 40 years. Aspen, paper birch, mountain ash, and mountain maple were significantly taller inside the exclosures than in browsed plots. Exclusion of browsing by moose also resulted in significant increases in litter depth in two of three exclosures, and in significant increases in six of eight soil properties: soil carbon, total nitrogen (N), cation exchange capacity, field nitrogen availability, potentially mineralizable nitrogen, and microbial respiration rates.

The long-term decline in nitrogen availability on Isle Royale may have subsequently shifted ecological carrying capacity for moose. For example, reduced nitrogen availability may delay the rate of recovery of shrubs from browsing, increasing the rate of re-invasion by spruces. Balsam fir is browsed so intensely that the historic fir-dominated forests are unlikely to return (Brandner and others 1990). Decline in soil nitrogen might cause browsed plants to produce greater quantities of secondary compounds (tannins), which may further impede herbivory by depressing digestive functions (Bryant and Chapin 1986). Such changes may also depress soil microbial activity, further reducing nitrogen availability (Pastor and others 1988). The moose population probably would decline in the absence of major disturbances to the conifer overstory, resulting in a new ecological carrying capacity.

Studies show that browsing by white-tailed deer reduces the abundance of certain conifers (Frelich and Lorimer 1985, Marquis 1981), and reduces thickness of the litter layer on the forest floor in eastern deciduous forests and mid-western northern hardwood-hemlock forests. Conversely, Ross and others (1970) found that high densities of white-tailed deer in Minnesota forests promoted dominance by conifers that were not browsed, including red pine and eastern white pine. Allison (1990) found that deer negatively influenced the reproductive biology of plants such as Canada yew.

Herbivory by cattle also alters the frequency and intensity of wildfires (Madany and West 1983, Zimmerman and Neuenschwander 1984) by removing fine fuels. Herbivory by wild ungulates may have similar influences. Also, grazing by large ungulates can cause nutrient losses from ecosystems via ammonia volatilization (Reuss and McNaughton 1988, Schimel and others 1986).

In summary, the ecological literature indicates that large-mammal herbivory can significantly influence forest ecosystem processes through effects on vegetation composition and productivity, successional rates, and soil-nutrient concentrations. If such patterns are common consequences of long-term herbivory by large ungulates, they should be observable in the Blue Mountains, at least in areas where ungulate populations are high relative to the available forage resources. Potential effects of long-term herbivory by elk and cattle populations in the Blue Mountains are predicted from the literature (table 3).

Table 3—Potential influences of long-term grazing by elk and cattle on ecosystem structure and function in eastside forests of Oregon and Washington

Influence	Selected references
Modify understory composition	Gessaman and McMahon 1984, Pastor and others 1988
Modify understory productivity	Gessaman and McMahon 1984
Alter dominance of conifers	Ross and others 1970, Pastor and others 1988
Alter habitat for other wildlife	Naiman 1988
Alter fire ignition potential	Madany and West 1983, Zimmerman and Neuenschwander 1984
Reduce litter depth	Pastor and others 1988
Compact soils	Crawley 1983
Alter nutrient cycling, energy flow	Gessaman and MacMahon 1984, McNaughton and others 1988
Reduce soil N availability	Pastor and others 1988
Alter cation-exchange capacity	Pastor and others 1988
Depress soil microbial activity	Pastor and others 1988
Decrease soil carbon	Pastor and others 1988

Observed Effects of Large Herbivores on Plants and Soils in the Blue Mountains

Studies with herbivore exclosures in and near the Blue Mountains Ecoregion provide insight on the effects of livestock and big game herbivory on understory vegetative composition (Edgerton 1987; Krueger and Winward 1974, 1976; Tiedemann and Berndt 1972; Zimmerman and Neuenschwander 1984), soil fertility (Tiedemann and Berndt 1972), and establishment and growth of tree seedlings (Kingerly and Graham 1990; Weigand and others, in press).

Exclosure studies show that excluding large herbivores results in increases in shrubs. Edgerton (1987) found that shrub cover increased 4-fold in an exclosure in a clearcut grand fir community in northeastern Oregon, but shrub cover outside the exclosure remained relatively constant over an 11-year period. At the same time, grasses increased about 4-fold outside and remained constant inside the exclosure. The effects of grazing on forb production were minor, although forb composition differed between treatments.

Tall shrubs, including Scouler's willow, mountain ash, and mountain maple, and shrubs of medium height, including thimbleberry, Utah honeysuckle, and big huckleberry, were common inside the enclosure but were virtually absent outside by the end of the 11-year period. These changes occurred in the absence of livestock grazing.

Tiedemann and Berndt (1972) reported cover of shrubs averaged five times higher inside an enclosure than outside, whereas cover of herbs did not differ significantly. Their observations occurred where an enclosure was maintained for 30 years in a Douglas-fir community that was clearcut near Wenatchee, Washington. Snowbrush *ceanothus* and chokecherry accounted for most differences in shrub cover. Big game, primarily mule deer, and livestock, primarily sheep, grazed the plant community outside that enclosure. Krueger and Winward (1974, 1976) reported 18 and 1.4 times greater cover of shrubs inside enclosures than outside, 12 to 14 years after excluding herbivores in northeastern Oregon. Enclosures in their studies were located in both a mature Douglas-fir-ponderosa pine community and in a selectively cut grand fir community, both of which were grazed by livestock and big game.

Additional information on the effects of herbivory on forested plant communities was collected in summer 1992 from four enclosures in the Blue Mountains between Elgin and Troy, Oregon (Tiedemann and others 1992). All enclosures were constructed about 25 years ago in climax grand fir communities in the Blue Mountains: two in clearcut stands, one in a partially harvested stand, and one in an old-growth stand dominated by grand fir. Results have not been summarized completely, but trends described above (a substantially reduced shrub component) were evident (fig. 7, A-F). Plot-based estimates during summer 1992 of four other clearcuts and cursory observations in 10 additional clearcuts that were created 10 to 20 years ago (fig. 8), combined with the available empirical evidence, suggest that suppression of shrubs by herbivores is widespread in the Blue Mountains.

Information on the effects of grazing on soil nutrient profiles apparently is limited to a single study by Tiedemann and Berndt (1972) of an enclosure near Wenatchee, Washington. The authors speculated that removal of shrubs, particularly snowbrush *ceanothus*, abundant only within this enclosure, might alter rates of nutrient accumulation in soils, because *Ceanothus* spp. can fix atmospheric nitrogen (Youngberg and Wollum 1976, Zavitkowski and Newton 1968). Tiedemann and Berndt (1972) found that herbivory reduced litter, which was 1.4 times greater inside than on the outside. Such differences suggest that soil fertility might differ too, but comparisons of soil fertility did not show significant differences. Long-term effects (for example, longer than one rotation) are unknown.



Figure 7A. Vegetation inside the Motett enclosure, about 18 miles north of Elgin, Oregon, July 1992. The enclosure was constructed in a grand fir community that was clearcut about 25 years ago. Nonconiferous vegetation is dominated by a variety of shrubs. Detailed assessment of vegetation characteristics was presented by Edgerton (1987).



Figure 7B. Vegetation outside the Motett enclosure, July 1992. Nonconiferous vegetation is dominated by bracken fern and western coneflower, both relatively unpalatable to tame elk in grazing trails (see text), and a variety of introduced and native grasses. Edgerton (1972) reported that livestock grazing was excluded from this site.

Herbivory can have important direct economic effects by influencing conifer seedling establishment and growth. Kingery and Graham (1990) examined conifer seedling establishment in three 1-acre exclosures in a Douglas-fir/mallow ninebark community west of Riggins, Idaho. They concluded that grazing by big game and cattle reduced seedling mortality from 35 to 15 percent by reducing competition from grasses and shrubs. Such benefits may be limited, however, because 25 percent of the injury and mortality to pine seedlings was attributed to trampling and browsing of seedlings by deer and elk. Rodents also caused injury to the pine seedlings. Rodent damage was greater inside the exclosures, perhaps because of an abundance of nonconiferous vegetation there.

Persistent grazing by herbivores throughout development of forest stands in the Blue Mountains may improve production of wood fiber by reducing competition from understory vegetation (Krueger and Vavra 1984; Weigand and others, in press; Wheeler and others 1980; Zimmerman and Neuenschwander 1984). If long-term herbivory reduces soil fertility (Pastor and others 1988), however, then removal of competing understory vegetation via herbivory may result in a net loss in the rate of wood-fiber production. Weigand and others (in press) present data supporting that hypothesis. They also suggested that herbivore-induced reduction of shrubs and concomitant increases in grasses and forbs may reduce regeneration of additional seedlings in established ponderosa pine stands.



Figure 7C. Vegetation inside the Hoodoo no-cut enclosure about 10 miles southwest of Troy, Oregon, September 1992. The enclosure was constructed in an old-growth grand fir community about 25 years ago. Understory vegetation is primarily dominated by shrubs such as mountain maple, thimbleberry, baldhp rose, and big huckleberry.

Collectively, these studies suggest that herbivory by large ungulates caused moderate to severe reductions of shrubs in a variety of logged and unlogged forest communities, and that elk and deer can have important effects in the absence of livestock. These studies also show that forest communities in the Blue Mountains respond relatively rapidly to reduced grazing pressure, requiring a decade or less for measurable effects to occur after ungulates are excluded. This ability of communities to respond to reduced herbivory might decline in the future, however. If intensive long-term herbivory suppresses shrub reproduction (Allison 1990), then the potential for natural regeneration of preferred shrubs might diminish as seeds in the soil lose viability. Substantial reductions in shrubs represent an important loss of plant biodiversity.

Studies have not clarified the effects of herbivory on soil fertility in the Blue Mountains, although the premise that reduced shrub abundance will eventually result in reduced soil fertility is reasonable. If soil fertility indeed is reduced, numerous ecosystem processes will be affected, with concomitant effects of production of commodities. If so, an appropriate objective in plans for restoring forest health might include regenerating shrubs and other understory vegetation.

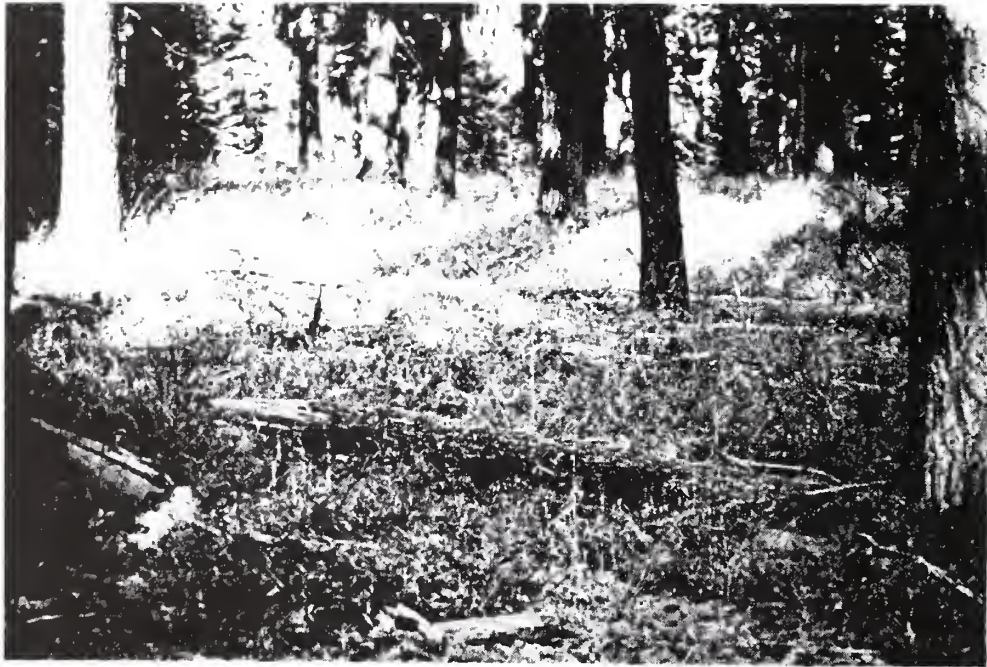


Figure 7D. Vegetation outside the Hoodoo no-cut exclosure, September 1992. Understory vegetation is dominated by low-growing forbs and shrubs, grasses, and common snowberry.



Figure 7E. Vegetation inside the Hoodoo clearcut exclosure, 10 miles southwest of Troy, Oregon, September 1992. This exclosure was constructed in a clearcut area in a grand fir forest stand 25 years ago. Nonconiferous vegetation is dominated by Scouler's willow, common snowberry, big huckleberry, and thimbleberry.



Figure 7F. Vegetation outside the Hoodoo clearcut enclosure, September 1992. Understory vegetation is dominated by a variety of grasses, low forbs, and shrubs.

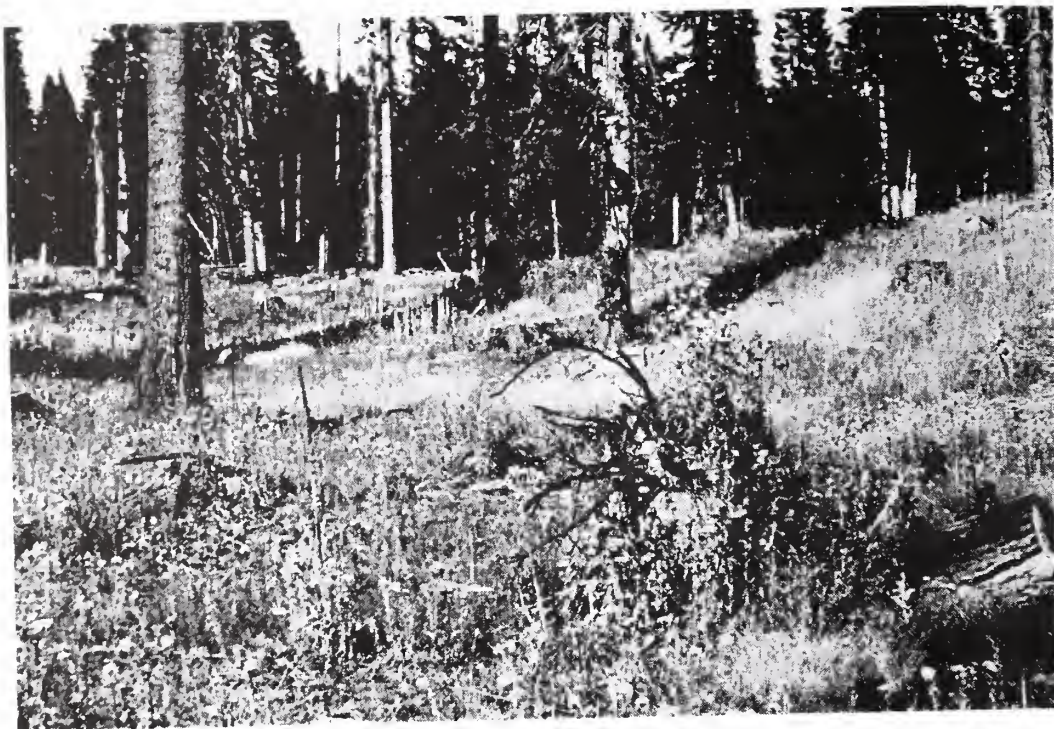


Figure 8. Clearcuts (10-15 years old) 18 miles southwest of Troy, Oregon, September 1992. Note the virtual absence of shrubs, which appears representative of most clearcuts in this area.

Predicted Feedback Effects of Herbivory on Large Ungulate Populations

The prevailing scientific opinion holds that the density of large wild mammals is limited by extrinsic factors, usually the condition of food supplies (Caughley 1987, Sinclair 1977, Sinclair and others 1985), predation (for example, Gasaway and others 1983), or both (Caughley 1976). Sinclair and others (1985) generalized hypotheses that related large-mammal density to forage resources as follows: mortality rate, which increases as population density increases, regulates populations through food shortages. This generalization includes the concept of density-dependence, in which factors that depress population growth act more forcefully as density increases.

In North America, density dependence is believed to occur most frequently in winter, when food is short relative to animal densities. Winter food shortage results in mortality by depressing birth weights and delaying dates of birth (Blaxter and others 1981, Thorne and others 1976, Verme 1969). In fact, Clutton-Brock and others (1987, 1988) and Choquenot (1991) concluded that juvenile mortality, through density-induced food shortage effects on birth weight and date, was the key factor regulating populations of red deer and feral donkeys, respectively. Experimental reduction in density of Rocky Mountain goats led to decreased age at first reproduction and to an increase in the number of young per reproducing female (Houston and Stevens 1988).

Although most work on density dependence has focused on winter food supplies, nutritional status in nonwinter seasons is also an important determinant of rates of birth, death, and growth among wild ungulates (Julander and others 1961, Klein 1970, Langvatn and Albon 1985, Reimers 1983). Lactating females require high-energy diets in the growing season to provide adequate milk for their young and to restore their own body weight before the next breeding season (Hudson and White 1985). Summer weight gain is important in reproduction because nutritional status may influence pregnancy rate and because it may influence the age when animals breed. Also, fecundity is related strongly to body weight for females that conceive (Albon and others 1983a, Bartle and others 1984, Clutton-Brock and others 1982, Mitchell and Brown 1974). Further, body reserves built up on summer ranges can determine how long juveniles and adults survive in the subsequent winter (Torbit and others 1985).

The relative influences of summer and winter nutrition on population dynamics of free-ranging large herbivores are unclear. Controlled experiments may be necessary (White 1983) to isolate the effects of numerous interacting factors. Experimental evidence indicates that female red deer on a low plane of nutrition directly after calving experience increased weight loss and produce less milk, which in turn, reduces the growth rates of their calves (Bartle and others 1984, Loudon and others 1984, Sadlier 1980). Mule deer fawns on marginal diets from the time of weaning through December were lighter in weight, deposited less fat, and exhibited reduced skeletal growth compared to fawns maintained on highly nutritional diets (Sadlier 1980). Hobbs (1989) related winter mortality in mule deer to nutritional status in prior seasons.

Fowler (1987) noted that information on density dependence can serve as indices of populations relative to the ability of the environment to support them. Thus, if long-term herbivory has affected plant composition and nutrient cycling in forest vegetation communities, then those changes should cause density-dependent, negative feedback effects to cattle productivity and elk population dynamics. If so, these effects are expected to become more pronounced as animal density increases relative to ecological carrying capacity (Fowler 1987).

Bunnell (1987) reviewed data from 155 populations of the deer family (Cervidae) and expressed the data in terms of simple models relating reproduction and mortality. He noted that elk are less susceptible than other deer species to early predation by virtue of the largest birth weights among the deer family. One consequence of this is that females require relatively high prenatal nutrition (Thorne and others 1976).

Another consequence is alternate-year reproduction among elk on poor ranges (Bunnell 1987). Thus, if density-dependent mortality or fecundity are affecting elk populations in the Blue Mountains, then elk should exhibit many of the characteristics listed in table 4 (adapted from Fowler 1987).

If long-term grazing by livestock and wild ungulates influences summer dietary quality, then several characteristics should be observed among cattle on summer allotments. Such characteristics include reduced growth rates among calves and reduced weight gains among adults compared to past years. Below, we review available evidence and observations from the Blue Mountains Ecoregion that relate to predictions about effects on forage quality, feedback effects on elk population dynamics (table 4), and cattle production.

Table 4—Potential density-dependent feedback effects to large mammal populations that may result from herbivore-induced changes in forage resources in the Blue Mountains

Effect	Selected references
Reduced adult reproduction	Cheatum and Severinghaus 1950, Knight 1970, Carbyn and others 1975, Staines 1978, Kie and others 1980, Clutton-Brock and others 1982, 1985.
Delayed sexual maturity	Buechner and Swanson 1955, Swank 1958, Teer and others 1965, Carbyn 1975, Staines 1978, Kie and others 1980, Houston 1982, Clutton-Brock and others 1985, Skogland 1985.
Reduced juvenile survival	Houston 1982, Sauer and Boyce 1983.
Reduced adult survival	Knight 1970, Carbyn 1975, Fowler and Barmore 1979.
Reduced growth, body size	Klein 1964, Staines 1978, Albon and others 1983a, Cook 1984.
Delayed mating, birthing	McCullough 1969, Kie and others 1980, Hanks 1981, Clutton-Brock and others 1982, Teer 1984.
Reduced antler size	Adams 1960, Clutton-Brock and others 1982, 1985.
Reduced length of suckling	Clutton-Brock and others 1985, Skogland 1985.
Changed diet composition	Kie and others 1980, McCullough 1984.
Skewed birth sex-ratio to females	McCullough 1969, Skogland 1986.
Skewed adult sex-ratio to females	Peek and others 1967, Clutton-Brock and others 1982, 1985.

Evidence of Feedback Effects on Ungulate Productivity in the Blue Mountains

No studies in the Blue Mountains have attempted to demonstrate density-dependent feedback interactions between wild herbivore populations and their food supplies. The first step in any such attempt requires assessing nutrient concentrations in forage and herbivore dietary quality. If nutrient content of large herbivore diets provides for optimal reproduction and growth, then the probability for negative feedback effects on animal productivity is low. If the supply of forage that meets nutritional requirements is not limited relative to herbivore densities, then the probability for negative feedback effects is also low.

When crude protein in forage on summer ranges in the Blue Mountains is compared to protein requirements of large mammals (fig. 9), forage quality appears adequate during late gestation, marginally adequate during early lactation, and inadequate from peak lactation (mid- to late July) through mid-autumn, although the data vary considerably among studies, forage classes, and the vegetative types from which data were collected. The data also suggest that big game may suffer from nutritional deprivation during late fall and winter, assuming 7 percent protein in forage meets requirements for maintenance (French and others 1955, Mould and Robbins 1981). Protein concentrations in forage in September and October were 7 percent or less, and likely declined further by early winter (assuming little or no fall "green-up" after fall precipitation). If so, big game must compensate in spring and early summer for inadequate protein consumption from late summer through winter. These data also identify the importance of birthing date: females that give birth in mid-May experience forage conditions superior to those of females giving birth in late June.

These observations on nutritional deficiencies in forage ignore the ability of ungulates to acquire high-quality diets by selective feeding. Large herbivores might compensate for such deficiencies by selecting plant parts and plant species of high quality. Empirical data from the Blue Mountains (fig. 9) suggest that livestock are unable to compensate, and summer-fall diet quality is inadequate (Skovlin 1962, Vavra 1983). Cattle weight gains were considered undesirable, and cattle often lost weight after mid-summer, particularly during years with sub-normal moisture. These studies have not determined that density-dependent feedback effects have reduced productivity of livestock or big game herds in the Blue Mountains; however, they describe a setting in which negative feedback effects might occur.

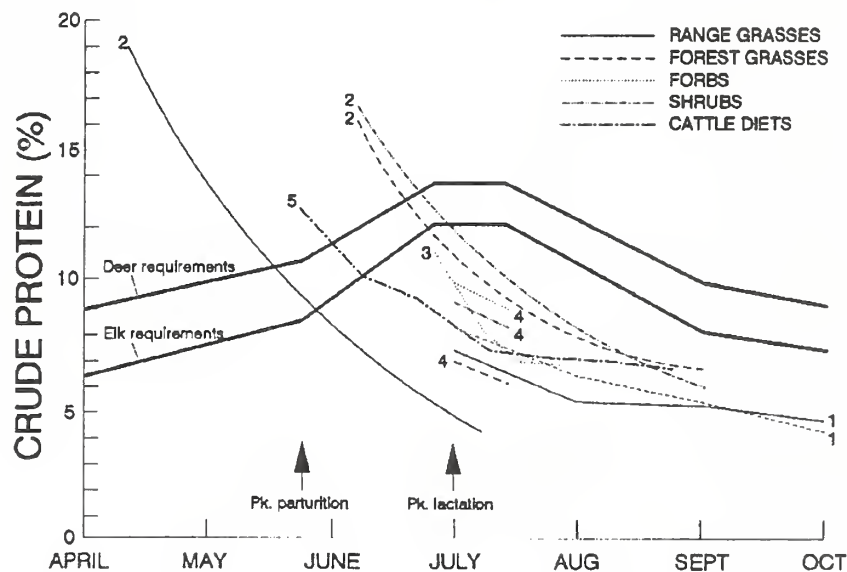


Figure 9. Crude protein of selected forage classes summarized from data sets collected in the Blue Mountains of northeastern Oregon. Numbers along lines identify source of data: 1—Skovlin (1967); 2—Svejcar and Vavra (1985); 3—J. Cook. (unpubl. data collected in 1990 in a ponderosa pine type at the Starkey Experimental Forests near La Grande, Oregon; 4—A. Tiedemann (unpubl. data collected in 1992 at 4 sites in grand fir types between Elgin and Troy, Oregon; 5—Cattle diets reported by Vavra (1983). Deer requirements were based on data for domestic sheep (a 60 kg ewe nursing a single lamb (NRC 1985), and elk requirements were extrapolated, using metabolic weights, from cattle requirements (NRC 1984) to a 250-kg cow elk with a calf. Both sets of requirements were modified to follow the late-gestation lactation curve for elk, described by Robbins and others (1981). Peak parturition (June 8) was based on birth dates of 64 elk calves born at the Starkey Experimental Forest (Irwin and others 1992), and peak lactation is assumed to occur 4 to 6 weeks post-partum (Robbins and others 1981).

Experimental studies were initiated in 1992 to assess summer foraging dynamics of elk, using two tame elk at four exclosures on elk summer range (Tiedemann and others 1992). Data were collected on dietary composition, foraging efficiency, and dietary quality using bite-count methods (Canon and others 1987, Wickstrom and others 1984).

Tall shrubs (such as mountain maple, mountain ash, Saskatoon serviceberry, Scouler's willow) and shrubs of medium height (such as thimbleberry, Utah honeysuckle, rose, and big huckleberry) comprised 80 percent of tame elk diets inside the exclosures, but comprised about 35 percent of the diets outside the exclosures (fig. 10). Elk concentrated their browsing on shrubs in May, where shrubs were available, even when grasses and forbs were abundant and likely of relatively high quality. Forage consumption rates tended to be higher inside the exclosures (fig. 11), although differences were not statistically significant. Elk foraging outside the exclosures consumed significantly less forage per meter traveled, particularly in September, and traveled at significantly faster rates than inside the exclosures. Thus, elk traveled greater distances to compensate for lower shrub availability outside the exclosures. This suggests that ecological carrying capacity is lower outside the exclosures where shrubs had been reduced by selective herbivory.

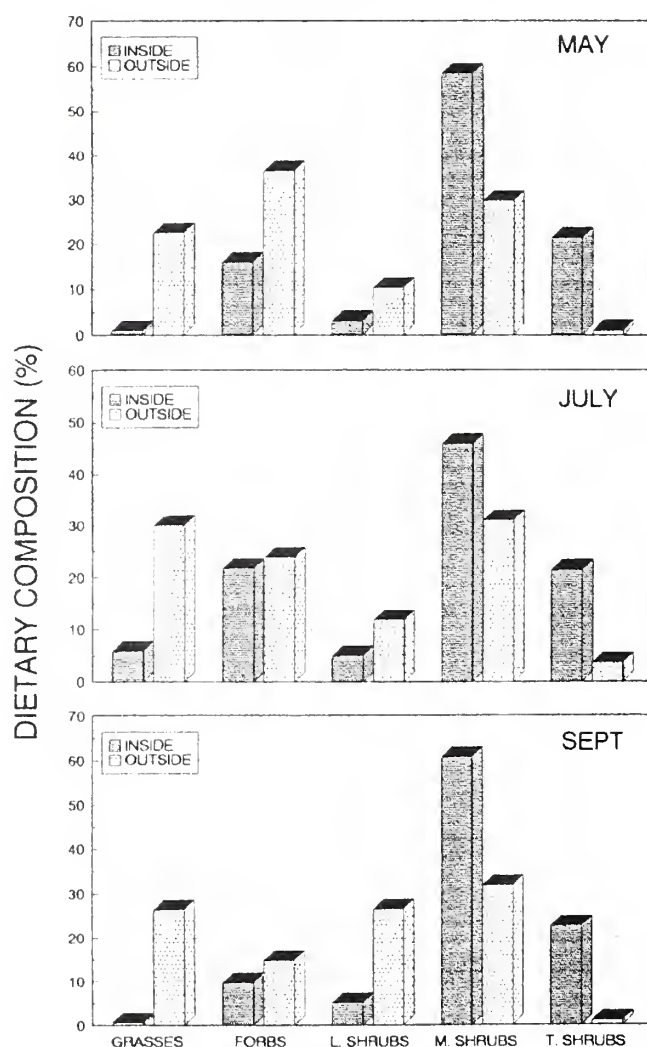


Figure 10. Dietary composition of two tame elk during 1992 in experimental grazing trials inside and outside four exclosures on elk summer range in the Blue Mountains between Elgin and Troy, Oregon. Differences between treatments (grazed vs. ungrazed), time sampling (May, July, and September), and treatment x time interactions were tested using multivariate, repeated measures ANOVA. The cattle- and big game-proof exclosures were constructed about 25 years ago in grand fir communities, two in clearcuts that now support sapling and pole-sized trees, one in a partial cut dominated by mature grand fir, and one in an old-growth stand of grand fir.

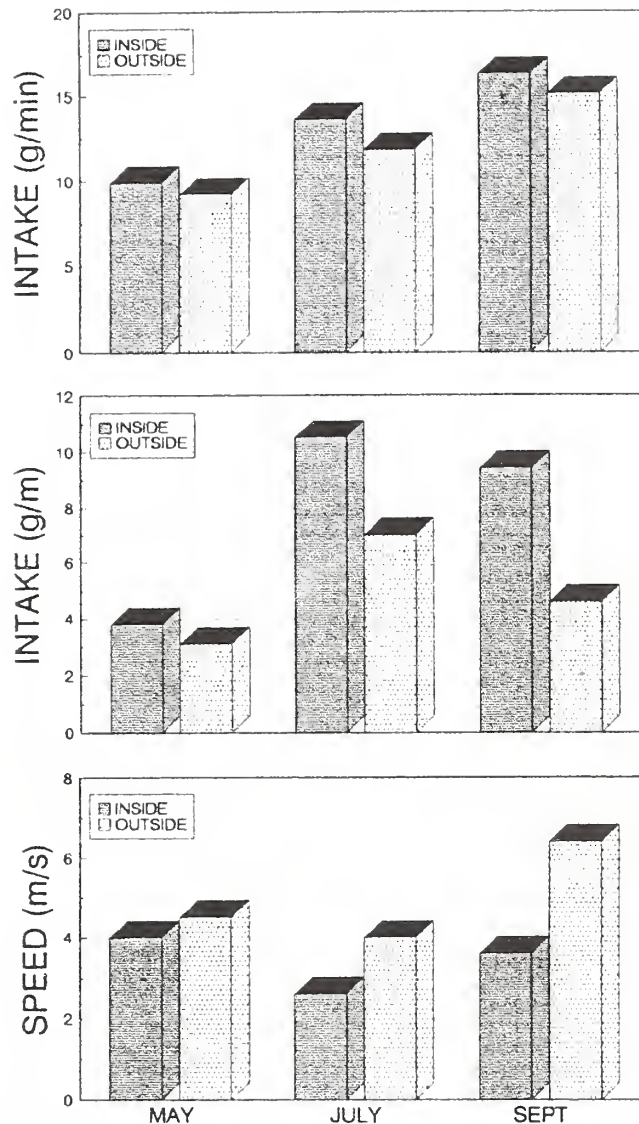


Figure 11. Foraging efficiency of two tame elk during summer 1992 in controlled grazing trials at four exclosures on elk summer range between Elgin and Troy, Oregon. Differences in forage intake per minute, forage intake per meter of travel, and rate of travel between treatments and among sampling dates are tested with multivariate repeated measures ANOVA.

Empirical data on forage quality and livestock nutritional status support a view that large herbivores subsist on suboptimal forage conditions most of the year in the Blue Mountains. Data from exclosures show that plant composition has changed substantially, particularly because of reduction in shrubs. Food habitats studies (Korfhage and others 1980) and tame-animal grazing experiments show elk prefer palatable shrubs. These studies support the premise that large herbivores are responsible for changes in plant species composition. Therefore, density-dependent negative feedback effects on productivity of large herbivores are highly probable in the Blue Mountains.

We have presented evidence of substantial growth of elk populations in the Blue Mountains over the last several decades. We also presented evidence that ungulates have altered the structure and composition of plant communities. These results predict that productivity of elk populations also has been altered, if ecological carrying capacity has been reduced and if ungulate densities remain high relative to carrying capacity. With this prediction in mind, we review evidence of density-dependent feedback mechanisms that may depress reproduction and recruitment of elk populations in the Blue Mountains Ecoregion.

Inverse relations between density and reproduction may be manifested in the reproductive rates for adult or yearling female elk (table 4). Little information has been published on the rate at which yearling elk breed successfully in the Blue Mountains. Buechner and Swanson (1955) noted, however, that the proportion of 2½-year-old females that were lactating increased from 21 percent in 1952 to 58 percent in 1954. Those data suggested that an increasing proportion of yearling females was becoming pregnant because lactation in 2-year-old females indicates conception as 16-month-old yearlings.

Buechner and Swanson (1955) hypothesized that the increase in yearling breeding had resulted from a dramatic increase in the number of elk that were harvested in 1949 and 1950. They concluded that the increased harvest had reduced the density of elk, thereby increasing the amount of food available to the remaining animals, enhancing their nutritional status, and increasing the incidence of yearling reproduction in subsequent years. Their results were the first to suggest density-dependent effects on reproduction in a Blue Mountains elk herd, almost 40 years ago. Although their results are cited as a classic example of a density-dependent response (Fowler 1987), their conclusion was derived from post-hoc observations and was thus highly inferential. Experimental manipulation of selected elk populations would test the veracity of Buechner and Swanson's (1955) results.

Juvenile survival should be reduced, if density-dependent mechanisms have influenced productivity of elk (table 4). Juvenile survival has not been monitored, but recruitment of calves into the yearling age-class has been monitored. Calf recruitment is a product of the birth rate and the juvenile survival rate. Thus, examining trends in calf recruitment could help clarify the potential for density-dependent effects on juvenile survival.

Long-term data on calf recruitment have been recorded by ODFW since 1953 (fig. 12). Calf recruitment clearly declined over a widespread area as density increased (see fig. 5). Rates of decline between population units associated with extensive wilderness areas (for example, Minam) are interesting when compared to those of units in which the forest has been intensively managed for commercial timber production (for example, Sled Springs). Lack of substantial differences does not demonstrate density-dependence, but it does suggest a common underlying mechanism that may supersede the effects of local land management practices. An ongoing analysis of unit-specific relations between density (fig. 5) and calf recruitment (fig. 12) suggests that calf recruitment declines are inversely correlated with elk density in a large subset of Blue Mountains elk population units (Riggs, unpublished).

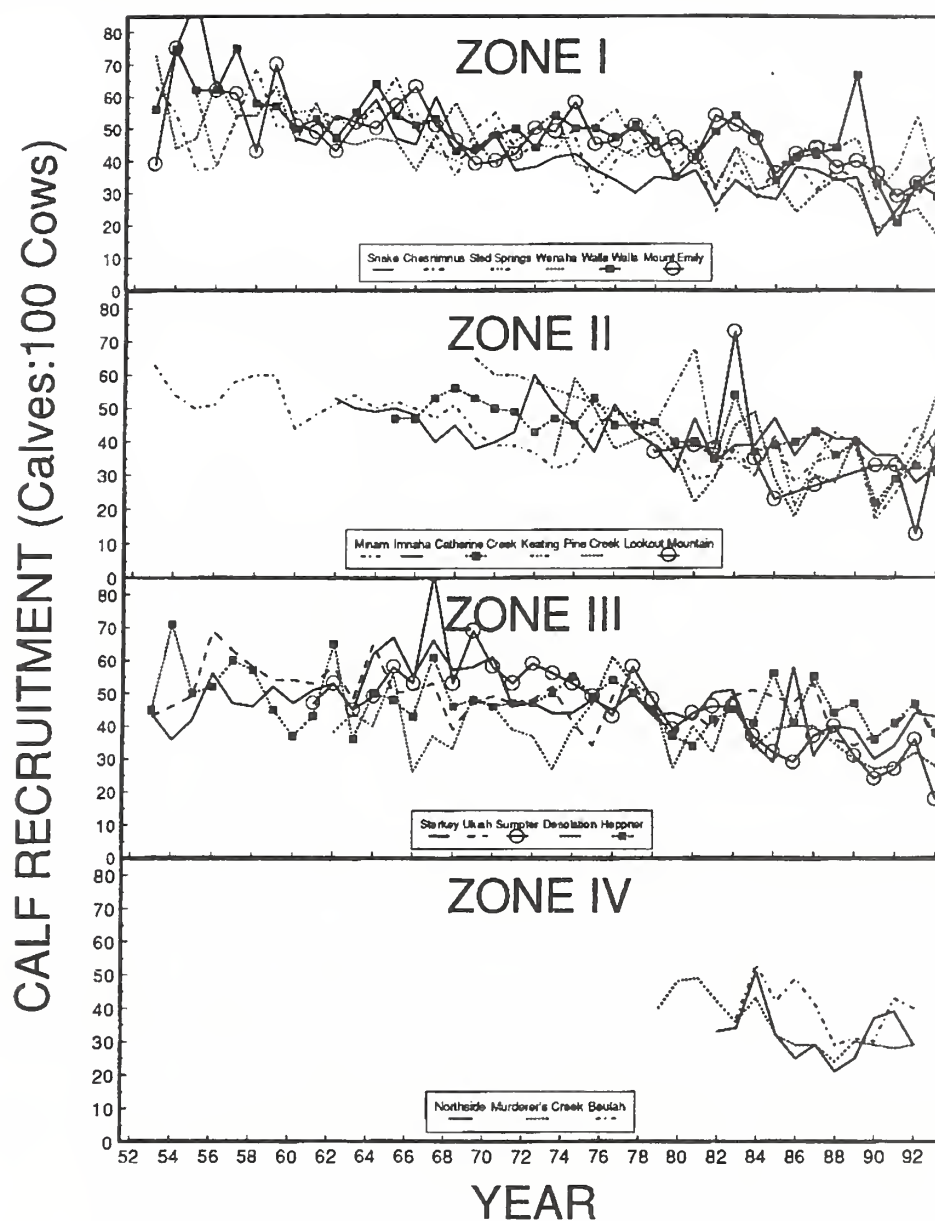


Figure 12. Annual elk calf recruitment estimates, by zone and unit, for the northeastern Oregon management area, 1953-92. Pre-1960 data points were derived by summing annual data for herd range samples that were nested within the boundaries of the current Game Management Units. Reprinted from Riggs (in prep.). Original data from Oregon Department of Fish and Wildlife annual reports, 1953-92.

DISCUSSION

Ungulate-vegetation interactions in the Blue Mountains are both complex and different from pre-settlement conditions. Vegetation composition, production, and diversity have been influenced by ungulates, fire control, insects and diseases, and historic logging regimes. Despite such complexity, evidence is clear that long-term herbivory by both wild and domestic ungulates has changed vegetation productivity in foothill winter ranges, montane grasslands, and understory vegetation in forest communities. Also, ungulates have facilitated dominance of annuals on some winter ranges (Vavra 1980). Forage quality in montane rangelands is below what is necessary for optimum growth of young deer, elk, and cattle. Tall shrubs have been reduced in clearcuts, selectively harvested stands, and unlogged timber stands.

Additional influences of herbivory on ecosystem processes are subtle. Ungulate grazing probably has altered nutrient cycling rates by transferring nutrients among forest and range communities, by volatilizing ammonia, and by reducing nitrogen-fixing shrubs. Herbivore-induced reductions in soil microbial populations and nutrient availability may have reduced growth rates of coniferous trees (Tiedemann and Berndt 1972). Also, ungulate grazing probably influenced the frequency of wildfire by removing fine fuels and shrubs, which affected the density of conifer regeneration, at least in the ponderosa pine and Douglas-fir zones. This reduced fire frequency could have acted to increase nutrient pools that might otherwise have been lower through heat-volatilization or leaching.

Evidence also suggests that herbivore-induced vegetation changes have interacted with other factors to produce negative feedback effects on productivity of elk populations and cattle. Cattle do not achieve desirable weight gains in summer allotments. Data on elk populations provide evidence of long-term declines in calf survival, which may be a manifestation of density-dependent juvenile mortality related to summer dietary quality and winter forage availability (Riggs, unpublished). Influences of poor summer dietary quality on elk calf survival may be exacerbated by low adult bull:cow ratios, which also cause delayed and lengthy birthing periods. The low bull:cow ratios resulted from high densities of elk hunters (Vales and others 1991) and increased vulnerability of bull elk to hunters after road building and alteration or reduction of cover from timber harvesting (Leckenby and others 1991). Quality of hiding cover for big game probably also has been reduced over time as shrubs were removed by ungulates browsing in timber stands (for example, see fig. 7, A-F).

Mule deer populations in the Blue Mountains Ecoregion were high in the 1960s (Schommer 1991b), similar to observations in other western States. The large populations may have been due to the increase in shrubs that resulted from cattle grazing in the 1930s and 1940s (Urness 1976). Mule deer populations currently are much lower than in the 1960s, and suffer from low fawn crops (Schommer 1991b). Those declines might have been associated with successional trends in forage, some of which may have been caused by the deer themselves, as reported elsewhere (Caughley 1970, Rasmussen 1941). Low fawn crops might also be caused by increased predator populations (Schommer 1991b), although density-dependent factors could predispose fawns to predation. Dense elk populations could preclude increases in mule deer herds, too, by reducing shrubs on mule deer winter and summer ranges.

Reduced productivity of big game populations has led to restrictions on hunting (Leckenby and others 1991). The number of days that hunters spent hunting for deer and elk decreased by 350 percent and 210 percent, respectively, since 1973 on the Wallowa-Whitman National Forest (Schommer 1991a, 1991b). The opportunity costs of the reduced hunting were estimated at more than \$10 million in lost revenues to the local economy in 1990 (Schommer 1991b), based on dollar values for a day of deer or elk hunting.

Elk use has increased on private lands along with increased elk densities and increased roading and recreational use of the National Forests (Gowan and others 1989, Vavra 1980). Such use has resulted in damage on private lands, particularly in spring. Livestock producers have complained that, although cattle were reduced when drought reduced forage production, the big game hunting permits were not increased (Vavra 1980). On the other hand, cattle use elk winter ranges in summer and fall. Forage allocation among livestock and big game is therefore an important topic, particularly from the perspective of an altered vegetation-herbivore system. Thus, researchers are examining forage resource partitioning among cattle and elk (Johnson and others 1991).

Is the current herbivore-vegetation interaction sustainable? Answering that question requires that we address two concepts: grazing systems and economic carrying capacity.

Elk and livestock grazing systems on National Forests differ in important ways. Cattle are fed hay or other rations in winter at lower elevations, and their calves generally are born in March. Elk migrate to lower elevations after snow buries forage; their forage supplies are low on many winter ranges. Elk benefit from early green growth in spring, and their calves are born on transition ranges. Livestock may remain for lengthy periods on some summer ranges, particularly riparian zones. Elk may move to new foraging sites when forage supplies are reduced, because forage intake rate declines with declining forage biomass (Wickstrom and others 1984). Elk use a broader variety of slopes and vegetation communities than do cattle (Mackie 1970). Cattle numbers and distributions are controlled, but elk distributions vary with forage conditions, recreational use along roads, and perhaps social interactions with cattle.

The second concept requires that we determine whether long-term herbivory in the Blue Mountains Ecoregion has reduced economic carrying capacities. Big game and livestock populations might be sustainable at current densities, although productivity will continue to be low. Long-term trends in productivity might be masked by short-term fluctuations associated with variation in summer and winter precipitation. Also, the high mule deer populations of the 1960s are unlikely to return. Thus, the current plant-herbivore subsystem probably is not stable, and objectives should be evaluated carefully for densities of both domestic and wild herbivores.

We believe that the appropriate density of either elk or cattle is neither what is commensurate with wise land use, nor what is consistent with the continuing health of the forest. We believe so, because multiple solution-sets are possible for sustaining livestock and big game at differing rates of productivity. The appropriate densities should be specifiable—either indexed or measured—and vary with quality of diets (Hobbs and Swift 1985) that meet the long-term goals for the ecosystem (Caughley 1989). Informed choices can only be made by identifying options and assessing the social, economic, aesthetic, and environmental effects of each alternative.

Management programs will soon be developed to begin overcoming current forest-health problems. Prescribed burning, salvage timber harvests, insect control, adjustment of ungulate densities, and control of timber-stand densities and composition will probably be emphasized in the short term. The process of identifying optimal approaches for the long term will proceed faster by implementing more than one option and monitoring ecosystem responses (that is, ungulate and vegetation responses) in manipulative experiments (Irwin and Wigley 1983).

The recent practice of dispersing timber-harvest units and limiting their size was intended to optimize the arrangement of cover and open areas (Thomas and others 1979). Although such practices stem largely from social concerns for aesthetics, they also accord with elk/habitat models (for example, Thomas and others 1988b). The habitat recommendations maximize distributions of elk, which often feed in openings and rest in adjacent stands of timber (Irwin and Peek 1983, Skovlin and others 1989). This strategy probably maximized herbivory by both cattle and elk in harvested units and adjacent forest stands, thereby facilitating suppression of floral diversity and productivity in subsequent successional stages.

If timber harvest units were larger, their centers would be less used by elk (Thomas and others 1979), increasing the probability that seral shrubs in treated areas would escape intense browsing. Treating large blocks of damaged forests to allow for greater expression of understory vegetation might improve the quality of hiding cover in future stands, if such treatment blocks are at least the size recommended by Lyon and Canfield (1991). The harvested units could be managed for a few years by light or moderate grazing by livestock to reduce the effects of herbaceous vegetation on regenerating conifers (Krueger and Winward 1976, Zimmerman and Neuenschwander 1984).

Both prescribed burning and timber harvesting can stimulate soil-nitrogen mineralization (for example, Hobbs and Spowart 1984), which likely would improve the nutritional status of ungulates over the short term. Expression of potential benefits, however, depends on the scale of treatment relative to the ungulate densities. Further, intense and recurrent burning could result in increased loss of nutrient capital over time (Boyer 1987), resulting in a reduction in ecological carrying capacity. Large timber-salvage operations might help maintain current forage production, or even increase it, but bull elk escapement will continue to be a concern (Leckenby and others 1991). Closing roads in areas larger than 20 to 30 square miles (Irwin and Peek 1979) might increase escapement of bull elk during hunting seasons.

Our review has implications for the use of elk/habitat models in land-use planning. Habitat-effectiveness models (for example, Thomas and others 1988a, 1988b) probably should be modified to account for density-dependent effects on elk productivity. Such models should probably also consider long-term ecosystem changes caused by high densities of ungulates. Such models might also be modified to include vulnerability to mortality from hunting, as indicated by Christensen and others (1991) and Vales and others (1991).

High ungulate densities may prevent reaching objectives for elk calf recruitment, mule deer populations, and may conflict with goals for vegetation management on the Forests. We suggest a careful evaluation of the relative potentials for improving calf recruitment by enhancing winter ranges and reducing densities of cattle or female elk, or both. Although predators and low bull:cow elk ratios may play a role, altering the ungulate density-vegetation relation might facilitate achieving long-term goals for the Blue Mountains Ecoregion.

We have provided vignettes of the interactions between long-term grazing by large herbivores and forest ecosystem dynamics, but we cannot specify the magnitude of the potential effects on biodiversity, nutrient cycling, and other ecosystem processes. Although we have identified reasonable relationships that are supported by ecological literature and data, our emphasis on elk and cattle may oversimplify an exceedingly complex herbivore-vegetation-management system that includes multiple interacting factors. Examples include the extent that fire suppression and long-term grazing by domestic sheep have modified plant-herbivore relationships and the degree to which hunting has influenced elk-calf recruitment through reducing adult bull:cow ratios. Moreover, the compensatory influences of other forms of mortality, including predation and diseases are largely unexplored. Ultimately, linkages between scientists and those that monitor the effects of management should clarify these relationships. We provide the following philosophical overview that may lead toward an appropriate path for managers and researchers to follow.

Cattle could be used as a tool to modify condition of elk winter ranges (Anderson and Scherzinger 1975, Pitt 1986). For example, elk move to areas that are rested or deferred from livestock grazing (Skovlin and others 1976). Most elk winter ranges lie on private lands (Vavra 1980), so using cattle to improve them might require innovative economic incentives for private landowners. Public managers might consider improving transition ranges that lie on the Forest. Using well-executed cattle grazing to do so may help mule deer because of the evidence that periodic cattle grazing can improve quality and availability of forage for mule deer (Urness 1976).

Below, we list several topics that may identify potential options and provide for assessments by linking monitoring programs with research. In so doing, we advocate use of adaptive management experiments (Walters 1986), which imply simultaneously implementing several management options under rigorous experimental design (Irwin and Wigley 1993). We suggest that the Forest Service solicit proposals from qualified scientists to address the following questions:

- ☐ To what extent have plant composition and productivity of eastside forests been changed by persistent grazing by large ungulates?
- ☐ What are the relative contributions by domestic and wild herbivores to these changes?

- ☐ To what extent have ungulate-induced changes in plant communities altered the seasonal nutritional status and productivity of ungulate populations?
- ☐ To what extent do various management strategies for large herbivores affect long-term productivity of forest sites?
- ☐ How do frequency and intensity of prescribed fire and silviculture interact with ungulate grazing to influence soil-nutrient capital, plant community composition, site productivity, and associated productivity of large-mammal populations over time?
- ☐ What are the relative effects of density-dependent mortality and density-independent factors in regulating production and yield of big game populations in managed ecosystems?
- ☐ Can reduction in herbivore density reverse apparent declines in shrub production and juvenile recruitment to big game herds?
- ☐ What are the relevant scales and units of evaluation for integrating livestock and big game in ecosystem planning?

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APPENDIX A

List of Common and Scientific Names for Plants and Animals

Common Name	Scientific Name
Aspen	<i>Populus tremuloides</i> Michx.
Baldhip rose	<i>Rosa gymnocarpa</i> Nutt.
Balsam fir	<i>Abies balsamea</i> (L.) Mill.
Big huckleberry	<i>Vaccinium membranaceum</i> Dougl.
Bracken fern	<i>Pteridium aquilinum</i> (L.) Kuhn.
Canada yew	<i>Taxus canadensis</i> Marsh.
Cheatgrass	<i>Bromus tectorum</i> L.
Chokecherry	<i>Prunus virginianus</i> L.
Common snowberry	<i>Symphoricarpos albus</i> (L.) Blake
Elk	<i>Cervus elaphus</i> Linn.
Douglas-fir	<i>Pseudotsuga menziesii</i> (Mirb) Franco
Feral donkey	<i>Equus asinus</i>
Grand fir	<i>Abies grandis</i> (Dougl. ex D. Don) Lindl.
Mallow ninebark	<i>Physocarpus malvaceus</i> (Greene) Kuntze
Moose	<i>Alces alces</i> Gray
Mountain ash	<i>Sorbus americana</i> Marsh.
Mountain ash (west.)	<i>Sorbus sitchensis</i> Roen
Mountain maple	<i>Acer spicatum</i> Lam.
Mule deer	<i>Odocoileus hemionus</i> Rafinesque
Paper birch	<i>Betula papyrifera</i> Marsh.
Ponderosa pine	<i>Pinus ponderosa</i> Dougl. ex Laws.
Red pine	<i>Pinus resinosa</i> Ait.
Red deer	<i>Cervus elaphus</i> Linn.
Rocky Mountain maple	<i>Acer glabrum</i> Torr.

APPENDIX A (continued)

List of Common and Scientific Names for Plants and Animals

Common Name	Scientific Name
Rocky Mountain goat	<i>Oreamnos americanus</i> Rafinesque
Rose	<i>Rosa</i> species
Saskatoon serviceberry	<i>Amelanchier alnifolia</i> (Nutt.) Nutt.
Scouler's willow	<i>Salix scoulerana</i> Barrett ex Hook.
Snowbrush ceanothus	<i>Ceanothus velutinus</i> Dougl.
Spruce, black	<i>Picea mariana</i> (Mill.) B.S.P.
Spruce, white	<i>Picea glauca</i> (Moench) Voss
Subalpine fir	<i>Abies lasiocarpa</i> (Hook.) Nutt.
Thimbleberry	<i>Rubus parviflorus</i> Nutt.
Utah honeysuckle	<i>Lonicera utahensis</i> Wats
Western coneflower	<i>Rudbeckia occidentalis</i> Nutt.
White pine, eastern	<i>Pinus strobus</i> L.
White-tailed deer	<i>Odocoileus virginianus</i> Rafinesque
Yellow pine	<i>Pinus ponderosa</i> Dougl. ex Laws.

Historical and Current Vegetation Pattern
and Associated Changes in Insect and Disease
Hazard, and Fire and Smoke Conditions in
Eastern Oregon and Washington

by

John F. Lehmkuhl, Paul F. Hessburg,
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Ernesto Alvarado, and Robert E. Vihnanek

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INTRODUCTION

The health of forested ecosystems in eastern Oregon and Washington has been the subject of concern in recent years (Gast and others 1991). Land-use practices over the last 100 years have altered the natural disturbance regime and reduced ecosystem resistance to disturbances. Fire suppression, timber harvest, and livestock grazing are among the management practices that have contributed to changes in ecosystem character that are conducive to insect outbreaks and severe wildfires (Agee 1993, Gast and others 1991, Hessburg and others 1993, Johnson and others 1993, Martin and others 1976) (fig. 1). Other potentially negative effects of ecosystem change include local extinction of wildlife and native plants, and deterioration of ecosystem health (Agee 1993). These conditions are not pervasive, however, and some forests remain healthy and productive (Gast and others 1991).

Few scientific data describing current vegetation composition, structure, and landscape pattern can be used to assess the extent of the problem and the associated insect, disease, and fire hazards. Moreover, few data describe the historical scale and range of variation in landscape attributes and disturbance regimes. Scale and range of variation are key reference points for judging the scope and direction of change and for guiding ecosystem management (Risbrudt 1992). Research to acquire this information is guided by hypotheses or questions about the roles of fire, insects, diseases, and other disturbances in ecosystems.

Fire has been critical to maintaining ecological diversity (Agee 1981, 1990; Hall 1976). The ecological characteristics of a broad range of eastern Washington and Oregon terrestrial communities from dry sagebrush to mesic high-elevation subalpine environments are closely interwoven with recurring fires (Hopkins and Kovalchik 1983, Johnson and Clausnitzer 1983, Johnson and others 1993, Johnson and Simon 1987, Williams and Lillybridge 1983, Williams and others 1990). Variables influencing fire and its interactions with biotic and abiotic factors are so numerous and complex that no two fires could be duplicated in their characteristics and effects. Moreover, variability is an intrinsic and vital characteristic of ecosystems in eastern Washington and Oregon, and fire is crucial to maintaining that natural complexity.

Fire suppression since the turn of the century has resulted in disruption of natural fire cycles, causing a decreasing frequency but increasing intensity of fires (Agee 1993, Gast and others 1991). Surface fires tend to occur in dry and warm vegetation series, such as ponderosa pine¹ and dry Douglas-fir series, at relatively frequent intervals of 3 to 35 years (see Agee 1993 for review). These low-intensity fires influence vegetation composition and structure primarily at a stand scale. Low-intensity fires generally thin understories and result in the suppression of shade-tolerant and fire-intolerant Douglas-firs and true firs, and dominance of ponderosa pines in a parklike setting. Suppression of surface fires along with selective logging of overstory dominant pines often results in a change in the composition and structure of forest stands. Where ponderosa pine is a seral dominant, composition may shift from ponderosa pine to Douglas-fir and true firs, and stand structure changes from open-canopy, parklike conditions to dense overstocked stands with multiple canopy layers (Caraher and others 1992, Gast and others 1991). Within-stand heterogeneity, or clumpiness, decreases without the variability of fire effects on ground vegetation, and with increasing dominance and filling in of canopy gaps by shade-tolerant species (Agee 1993). Where ponderosa pine is a climax species, a dense understory of young pine develops.

Stand-replacement fires historically occurred with much less frequency than surface fires, primarily in the mesic and cool Douglas-fir, grand fir, and subalpine series with moderate-to-high fire-severity regimes. Hall (1990) found a stand-replacement fire frequency of 50 to 300 years in grand fir communities in the Blue Mountains. Studies reviewed by Agee (1993) show a fire return interval from 15 to 100 years in the grand fir series and 50 to 250 years in the subalpine fir series. The effect of stand-replacement fires is a shift in stand composition and age from multicanopy midseral stands to early-successional species, such as lodgepole pine and western larch.

¹ Scientific names for all taxa mentioned in text are given in Appendix D.

Fire behavior varies across the landscape as a result of the interaction of weather, topography, fuel conditions, and vegetation composition and structure (fig. 2). The predicted result of high natural fire frequencies and variability at the landscape scale is a mosaic of vegetation patches, the scale of which depends on the fire-severity regime. A mosaic pattern of fire effects is especially true for areas in moderate-severity fire regimes where variable weather and environmental conditions result in a patchwork of surface and stand-replacement effects (Agee 1993). The expected result of fire suppression is a more homogenous landscape, with relatively fewer vegetation types (less area in early successional stages), larger patches at lower patch densities, and less total edge than with natural fire cycles. Timber harvest may counteract the homogenizing effects of fire suppression by fragmenting forest cover at a landscape scale (fig. 3).

The simplification of forest stands with fire suppression and removal of dominant overstory trees by selective logging also increases the probability of insect and disease outbreaks (Hessburg and others, 1993). Increasing vertical and horizontal abundance of host species in forest understory increases host foliage volume and insect dispersal pathways (Gast and others 1991; Hessburg and others, 1993). High stem densities result in more competition and stress on trees and increasing susceptibility to insect and pathogen attack. Simplification of stand structure and increasing host continuity allow for more rapid spread of pests across landscapes. These conditions in eastern Oregon and Washington have resulted in dramatic insect outbreaks and tree mortality (Gast and others 1991).

Although the problems associated with fire exclusion are well known, little has been done to reintroduce fire to restore and sustain desired ecological characteristics and to circumvent problems compounded by fire exclusion. Many scientists, managers, and lay people accept that fire is an essential component in the dynamics and sustainability of fire-dependent ecosystems of eastern Oregon and Washington. A 3- to 5-fold increase in prescribed burning has been suggested for this area to restore the ecosystems to a more healthy state. Prescribed fire, where fires have been suppressed and fuel loads are high, is risky and produces smoke, which can degrade visibility, violate current air-quality standards, and affect human health. Some of these effects run contrary to current Federal and State laws and are extremely unpopular with the public. If fire is to be reintroduced into ecosystems, fire managers, air-quality regulatory agencies, and the public will need to understand fire behavior and the tradeoffs between prescribed fire, forest health, wildfire occurrence, and air quality. This knowledge will equip society to make informed decisions about managed fire versus future catastrophic wildfire, forest health, and air quality.

Knowledge of fuel complexes within a geographic area is the foundation from which fire behavior, consumption of dead biomass, and smoke emissions can be predicted. Understanding potential fire behavior allows managers to predict change in ecological characteristics if fires were to occur and to plan fire management activities, including control measures, fuel hazard reduction, risk assessments, and restoration of desired ecosystem attributes using fire. Significant changes in vegetation composition and structure that affect potential fire behavior over large geographic areas may indicate that fire processes within ecosystems are shifting. With such shifts, fire may have different ecological effects on biotic communities and abiotic resources. If so, new fire control and fuel reduction strategies should be crafted and implemented to achieve management goals and objectives for desired future vegetative conditions.

The objectives of this assessment are to describe historical (35-50 years ago) vegetation composition, structure, and range of variation of these attributes on a representative sample of National Forest lands in eastern Oregon and Washington; to describe current vegetation composition and pattern in that same sample and determine changes from historical conditions; to assess the effect of the measured changes in vegetation pattern on insect and disease hazard, the fire fuel complex, fire behavior, smoke management, and other resources; and to examine the natural processes and management activities, such as fire suppression and logging, that may be driving observed changes in landscape pattern.



Figure 1—Time-series photographs from the Lakes Lookout divide west of Anthony Lake, Wallowa-Whitman National Forest, Oregon. Photographs were taken looking west toward Trail Creek.

Top—1922: notice the open forest on the hillsides in the left background; **Middle—1974:** noteworthy changes are the greatly increased tree cover on the hills in the left background, the newly established sapling trees in the meadow and the erosion caused by excessive sheep grazing in the rocky area of the meadow in the foreground; **Bottom—1992:** heavy insect mortality in the hills in the left background left thousands of acres of dead standing trees; large burned areas in the background are not visible in photograph; however, note negligible change in the open near hillside. Photos and information provided by Jon Skovlin, Cove, Oregon.

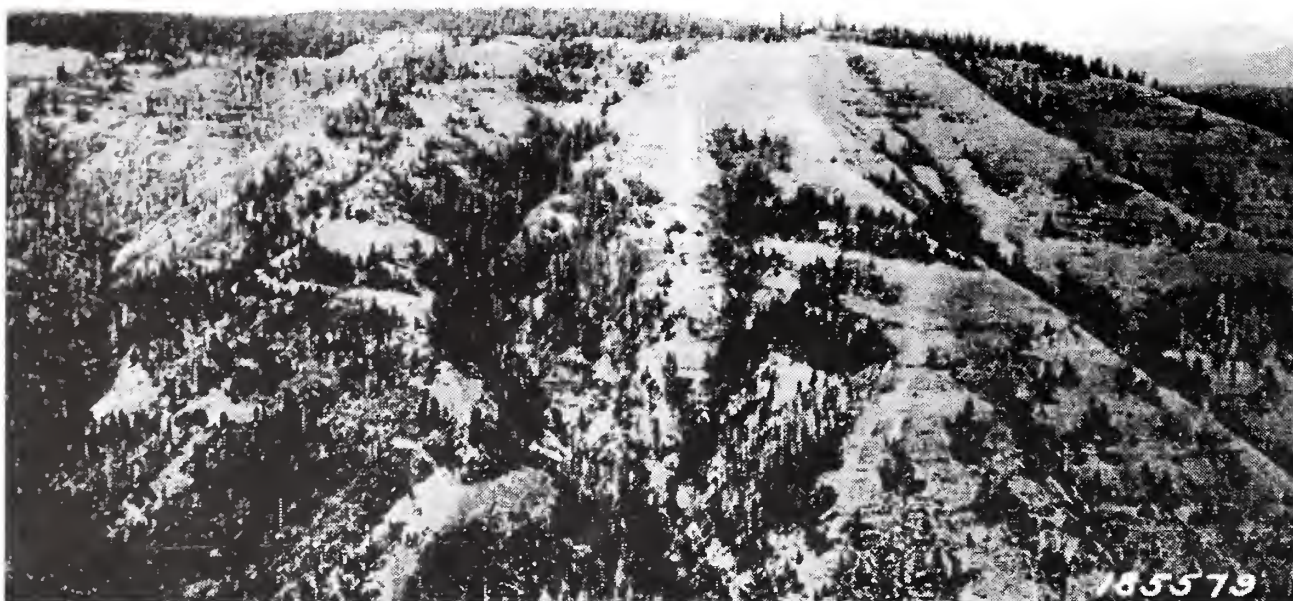


Figure 2—Time-series photographs from Looking Glass overlook, Wallowa-Whitman National Forest, Oregon. Top—1924: small fires have burned unevenly up the canyons leaving burned and unburned patches, but have completely burned the canyon on the far left side. **Bottom—1992:** note that the basic pattern of vegetation has not changed, but formerly burned areas have regenerated and patches intact in 1924 are larger and more homogeneous. Photos and information provided by Jon Skovlin, Cove, Oregon.

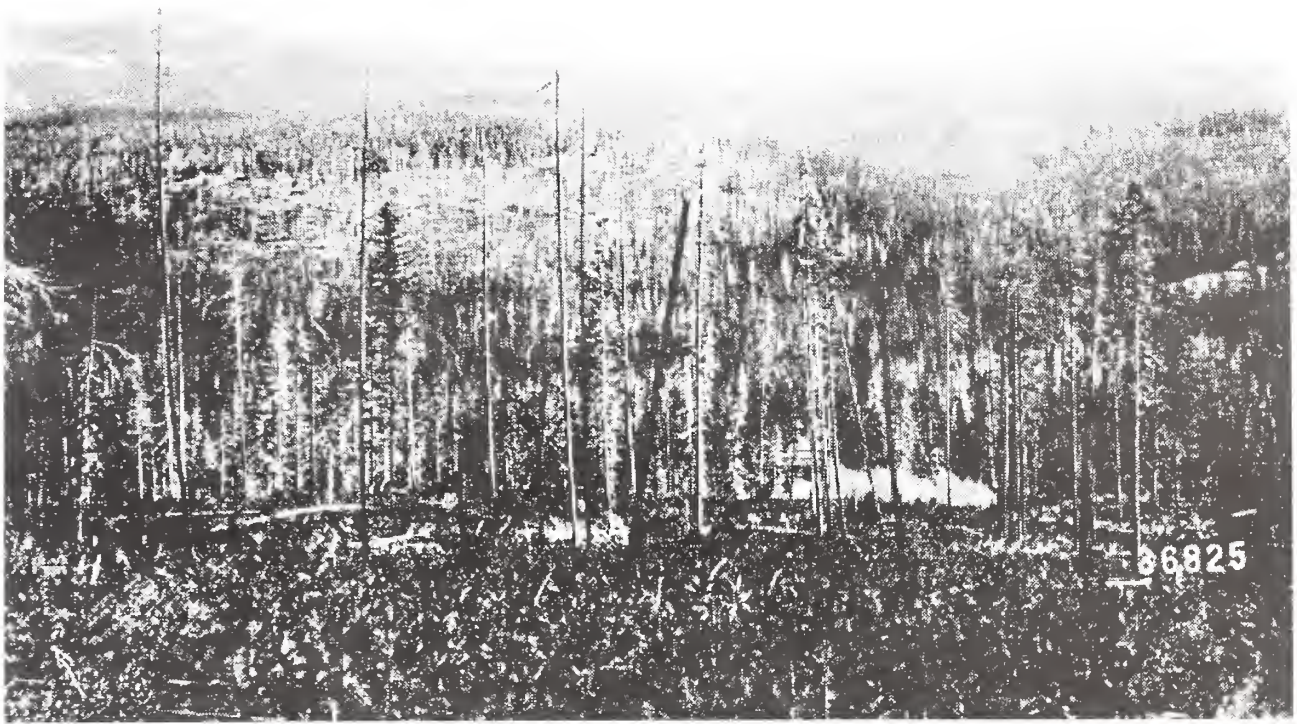


Figure 3a—Time-series photographs of the North Fork Trail Creek, opposite Chicken Creek, between the Grande Ronde and John Day river basins, Wallowa-Whitman National Forest, Oregon. Top—1902: areas burned during 1889 are evident in the foreground and mid-ground; ridgetops in the background are quite open; **Bottom—1967:** a new lodgepole pine stands has grown in the burned areas among the western larch that survived the fire; landscape pattern is relatively homogeneous; and ridgetop meadows have diminished.

(continued next page)



Figure 3b—Top—1982: salvage timber harvest of trees killed by western and mountain pine beetle begins to break up the homogeneous landscape. **Bottom—1992:** large fires in the late 1980's burned much of the middle distance and background. Photos and information provided by Jon Skovlin, Cove, Oregon.

In our assessment, we explored questions concerning changes in eastern Oregon and Washington vegetation conditions and associated changes in hazards from insects, diseases, fires, and smoke.

Vegetation composition and stand structure:

- ☐ Has the proportion of eastside landscapes with early successional species as overstory dominants decreased as the proportion of shade-tolerant species increased?
- ☐ How has stand vertical and horizontal structure and understory species composition changed?
- ☐ Has vegetation pattern become less diverse at the landscape scale?
- ☐ How has timber harvest affected landscape pattern?
- ☐ Have landscape-scale changes in vegetation composition and pattern been most evident at the scale of river basins or at the smaller scale of watersheds?
- ☐ What is the historical range of variation in vegetation composition and structure?

Insect and disease hazards:

- ☐ Have shifts in stand and landscape-scale composition and structure resulted in increased hazard from insects and diseases?
- ☐ How have changes in landscape pattern affected insect and disease dynamics?
- ☐ At what scale are changes in insect and disease hazards most evident?

Fire and smoke management:

- ☐ How have fuel loadings and potential fire behavior changed between historical and current landscapes?
- ☐ Have management activities influenced potential fire behavior characteristics?
- ☐ How have smoke emissions changed over time?

We will examine these questions through analysis of historical and current vegetation composition and pattern, associated insect and disease hazard, fire behavior, and smoke production in sample watersheds within six river basins. These river basins are meant to represent the five forested ecoregions of eastern Oregon and Washington. We will also discuss the possible relation between historical land use and our results, considerations for future management, and questions that can be answered by further analysis of these and supporting data.

METHODS

Study Areas

Each of the six river basins we sampled represented conditions in a major forested ecoregion (Omernik and Gallant 1987) of eastern Oregon and Washington (fig. 4). The Pend Oreille River basin in northeastern Washington represented the Northern Rocky Mountain ecoregion. The Methow River basin was typical of the Okanogan Highlands described by Franklin and Dyrness (1973), which was not included in the Omernik and Gallant (1987) classification, but which we believe was sufficiently distinct in geology, physiography, and environment to warrant separate analysis. The Cascades ecoregion was represented by the Wenatchee River basin and the northern portion of the Yakima River basin in the Cle Elum Ranger District. The southern part of the Yakima River basin was indicative of the northern end of the Eastern Cascades and Foothills ecoregion. That ecoregion was primarily represented by the Deschutes River basin south of the Metolius River and within the boundaries of the Deschutes National Forest. The Grande Ronde River basin represented the Blue Mountain ecoregion of northeastern Oregon and southeast Washington.

A prime consideration in choosing the Methow, Wenatchee, Yakima, and Grande Ronde basins was our desire to pair the terrestrial analysis, with the aquatic analysis of those basins (McIntosh and others 1993). One selection criterion for all basins was that a large portion of the basin should be managed by the U.S. Department of Agriculture, Forest Service, because the assessment would be confined primarily to lands within the current boundaries of National Forests. Also, similar resource data would be more available from Forest Service lands than from a mosaic of Federal and other ownerships. Finally, we calculated that six basins were the most we could analyze with the available time and resources for the project.

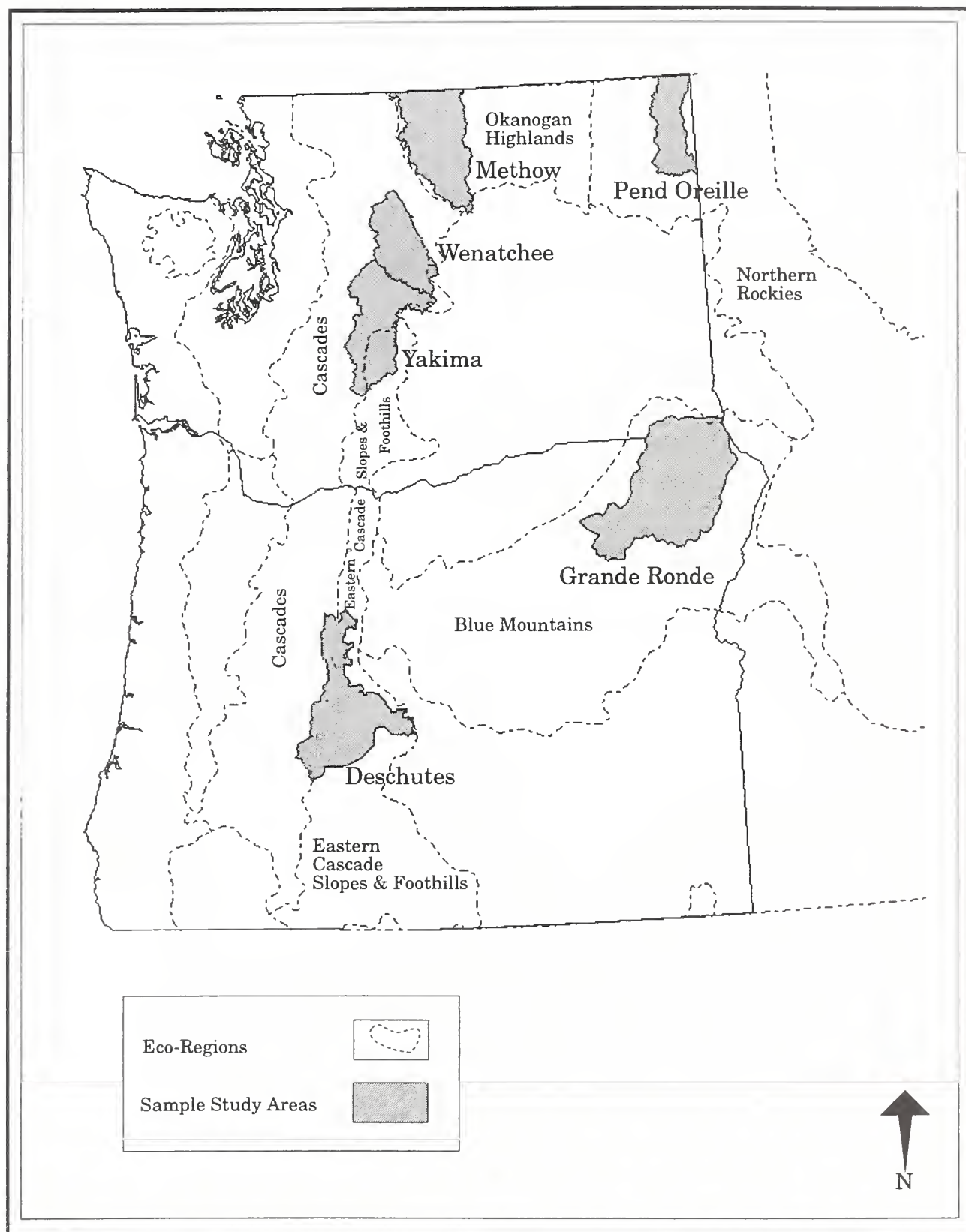


Figure 4—Forested ecoregions of eastern Oregon and Washington and six river basins sampled for the eastside forest ecosystem health assessment during 1993.

Sampling Design

We divided the portion of each river basin within National Forest boundaries into sample watersheds having a mean 8875 ha (range 5100 to 13,500 ha) using existing watershed maps from National Forests, or by drawing them from National Forest maps where watershed maps were currently unavailable. We sampled watersheds instead of the area within regular-shaped sample frames, such as a square or circle, because vegetation pattern created by environmental and disturbance gradients would more closely follow the ridgeline and stream boundaries of watersheds than an arbitrary regular shape. Boundaries of vegetation patches would be less likely to be truncated in watershed samples than in circular or square sample frames placed at random over the study area, thus yielding more realistic measures of landscape pattern.

A potential problem with using sample units of differing sizes, such as watersheds, was the well-known correlation of some landscape pattern attributes and map extent (area) (O'Neill and others 1988, Turner 1989). Studies of forest pattern in western Washington, however, have shown that sample estimates of landscape attributes change asymptotically rather than linearly. Lehmkuhl and Raphael (1993) found most landscape pattern variables differed significantly when map extent increased from 2000 ha to 3250 ha around fixed locations, but few variables differed in value between 3250-ha and 7325-ha landscapes. We believe that sample watersheds of about 8000 ha would result in little or no bias from different-sized sample units.

We used stratified random sampling to select watersheds within river basins for analysis. Each river basin was stratified into two to eight subbasins, depending on basin area, to distribute samples evenly across the basin. Sample watersheds were allocated randomly within subbasins to sample 25 percent of the watersheds and 25 percent of the area in each subbasin, which we estimated would yield a highly representative sample and was feasible with project resources. We initially selected a random 25-percent sample of the watersheds in subbasins, then selected an additional random sample of watersheds if the initial sample area was < 25 percent of the subbasin area. In the event we were unable to process all sample watersheds for this report, we randomly designated first-priority watersheds within each subbasin (figs. 5-10) that yielded about a 15-percent sample. An assessment of landscape change in these first-priority watersheds is presented in this report; the other sample watersheds were mapped and will be analyzed subsequently.

Vegetation Mapping

Vegetation mapping required high-quality map data for both current and historical periods. The project assignment dictated using existing data where available, but the data had to be of sufficient quality for a credible scientific assessment. We set mapping standards to evaluate the quality of existing vegetation datasets: vegetation units were mapped at a minimum size of 4 ha; vegetation patches were defined by ecological attributes of patch composition and structure that were critical for assessment of fire, insect, and disease risk (for example, multiple canopy layers); vegetation patches were described by multiple attributes of composition and structure, that is, not one or two descriptive names like "old growth" or "Douglas-fir large sawtimber," so attributes could be used independently or in combination for analyses of change in landscape pattern, fire hazard, and insect and disease hazard and for later analyses of dynamics; vegetation units were mapped for both current and historical periods by using the same standards and attributes of patch composition and structure; map data verified in the field were preferred, but we would accept expert opinion where necessary to complete the project; current and historical map data were available for all study areas no later than January 31, 1993, and preferably sooner.

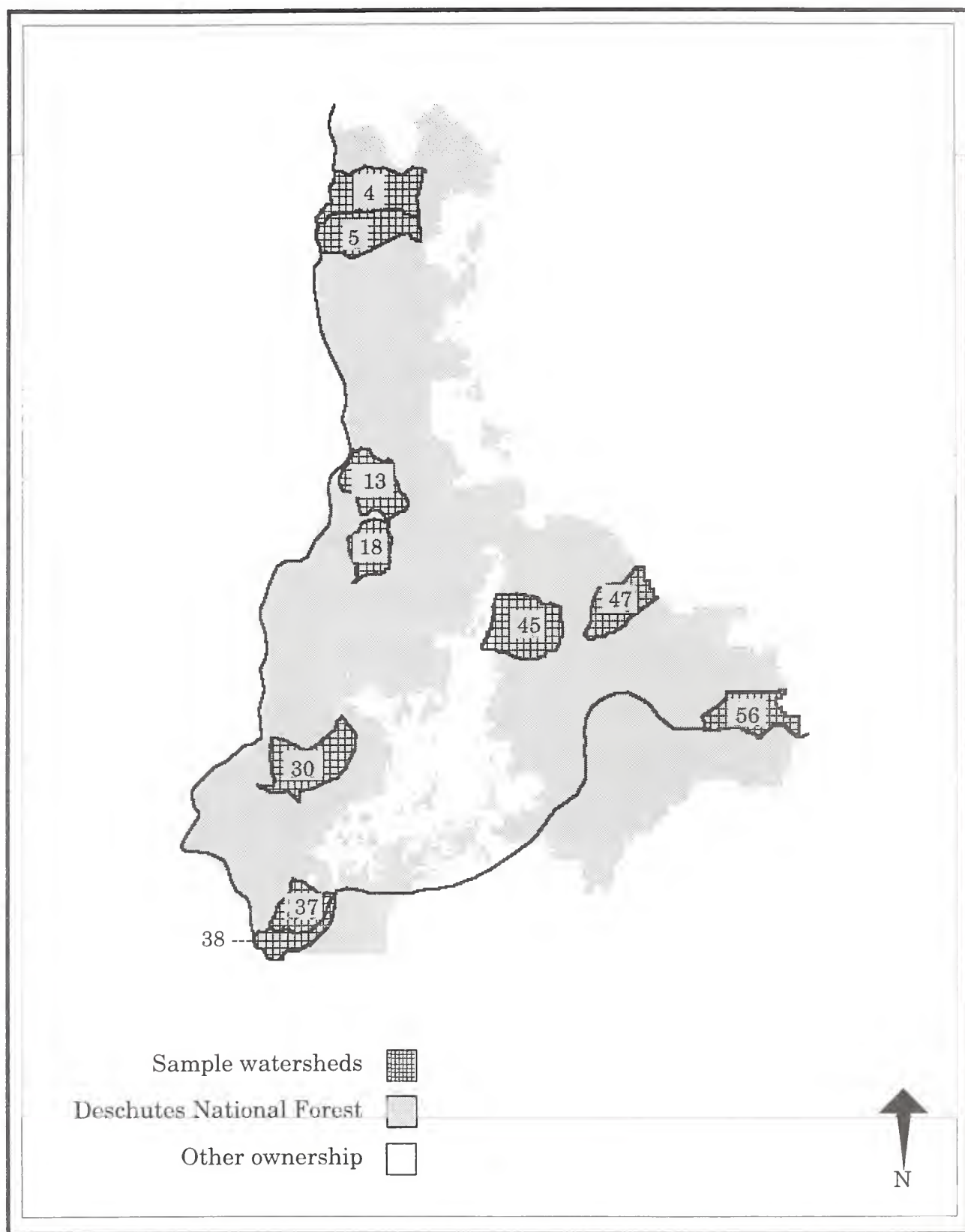


Figure 5—Watersheds on National Forest and other ownerships sampled for the eastside forest ecosystem health assessment in the Deschutes River basin, Oregon, 1993.

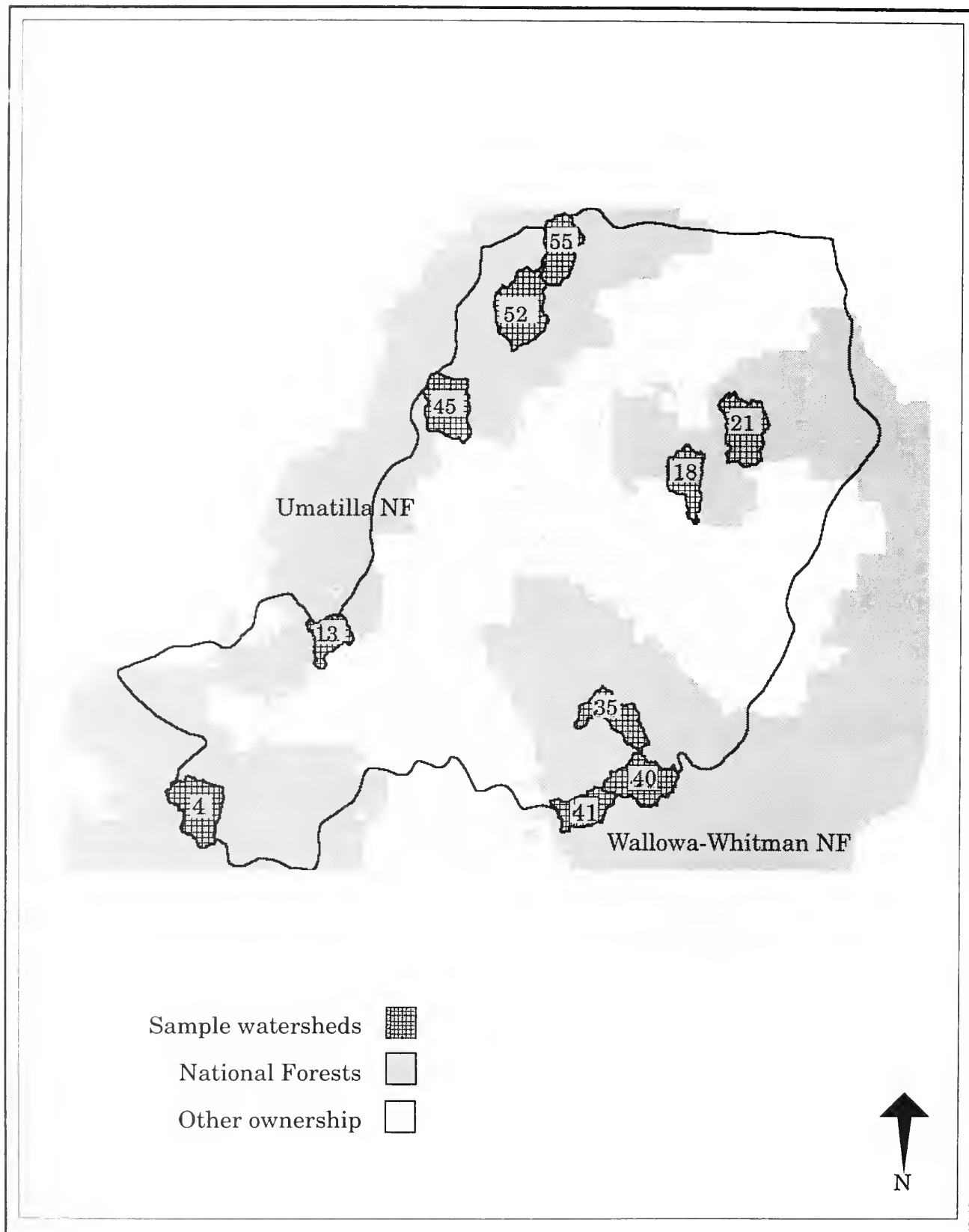


Figure 6—Watersheds on National Forest and other ownerships sampled for the eastside forest ecosystem health assessment in the Grande Ronde River basin, Oregon, 1993.

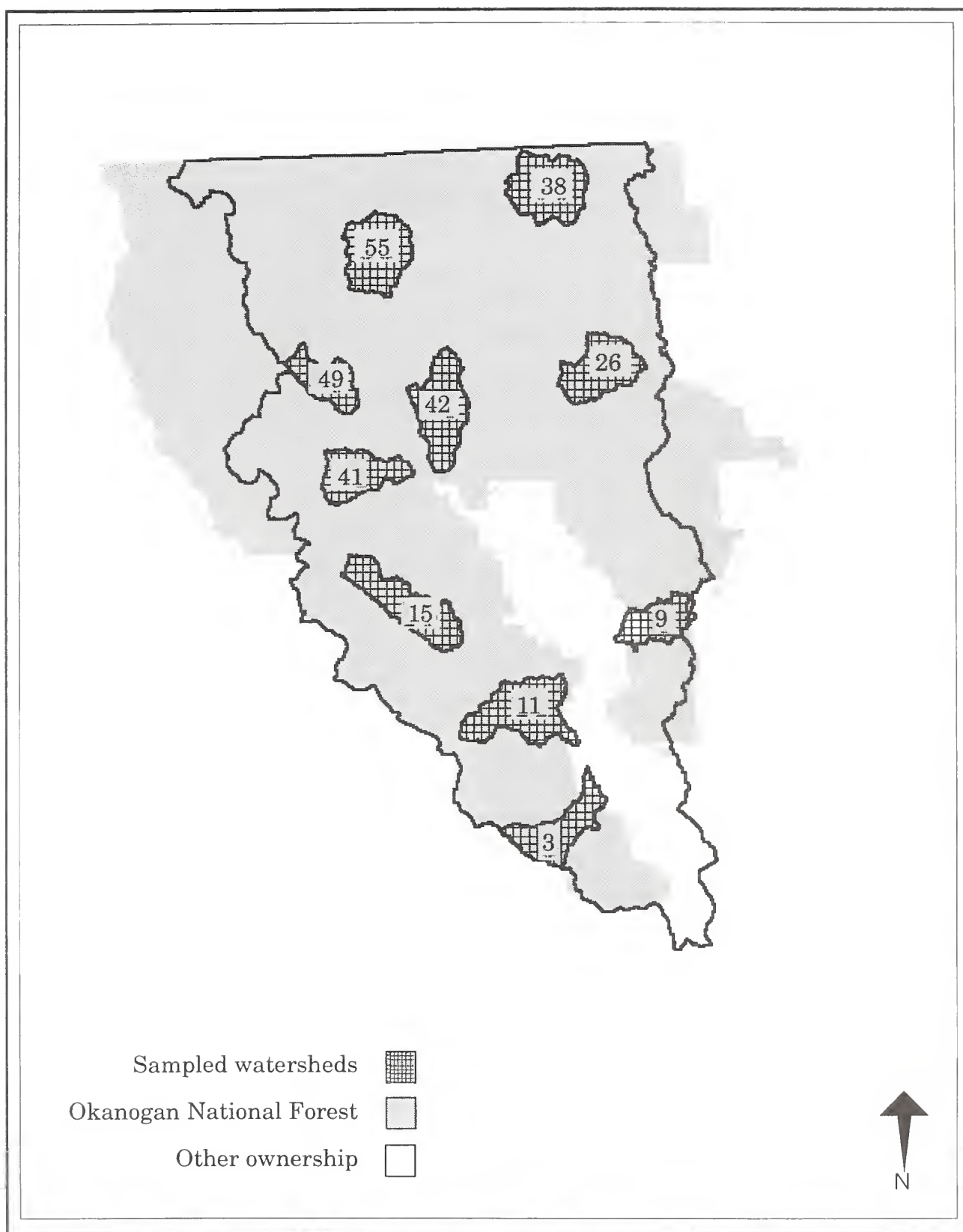


Figure 7—Watersheds on National Forest and other ownerships sampled for the eastside forest ecosystem health assessment in the Methow River basin, Washington, 1993.

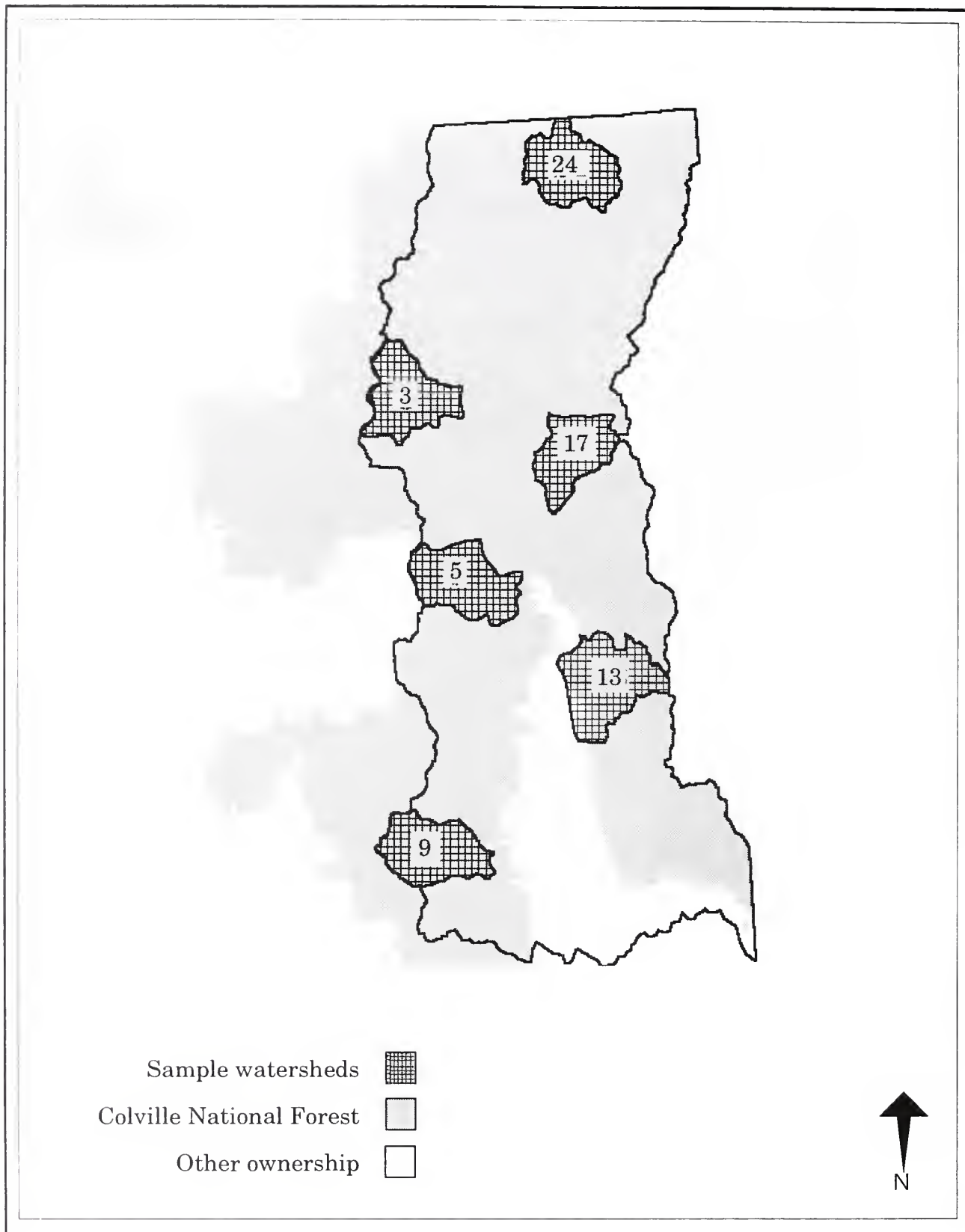


Figure 8—Watersheds on National Forest and other ownerships sampled for the eastside forest ecosystem health assessment in the Pend Oreille River basin, Washington, 1993.

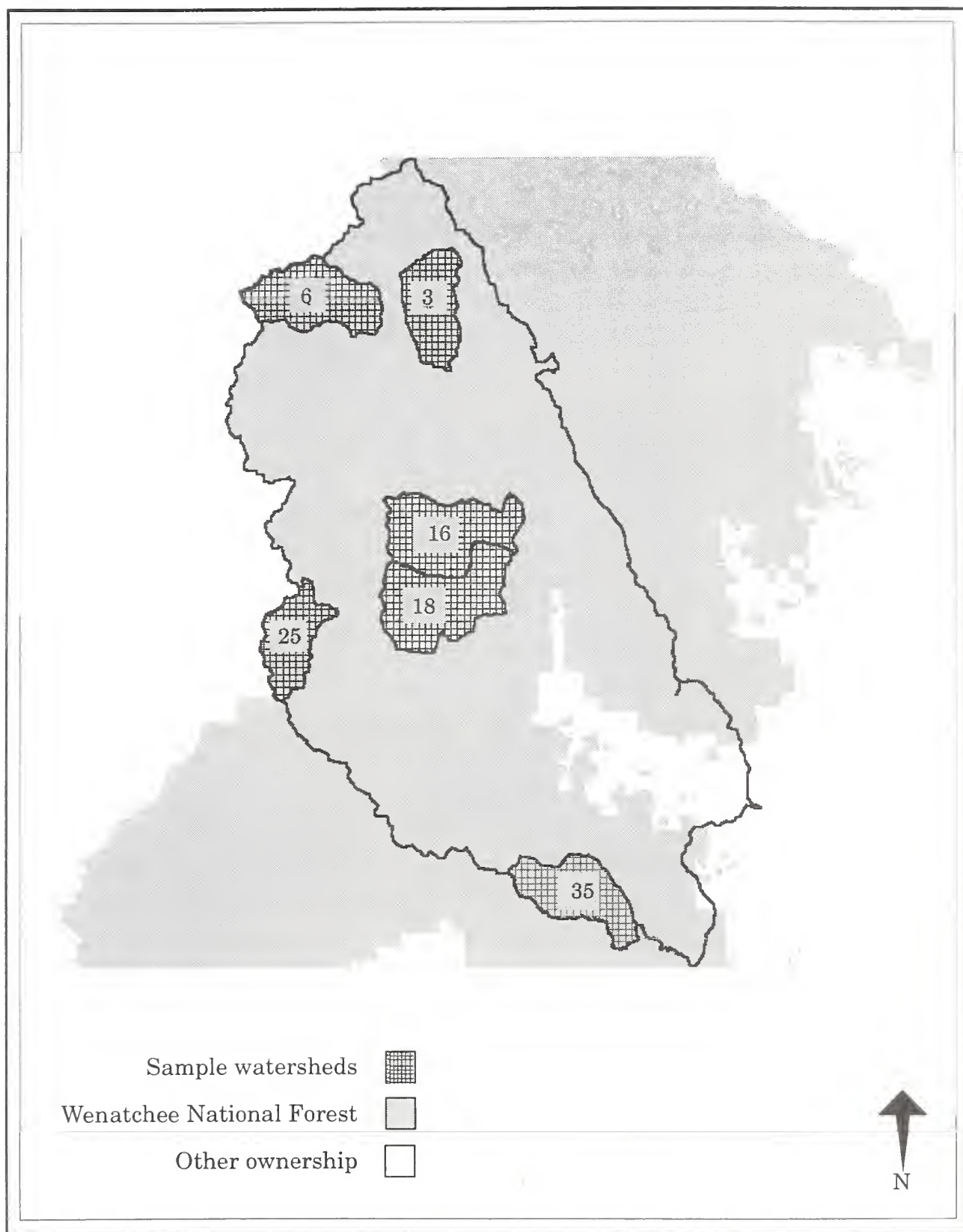


Figure 9—Watersheds on National Forest and other ownerships sampled for the eastside forest ecosystem health assessment in the Wenatchee River basin, Washington, 1993.

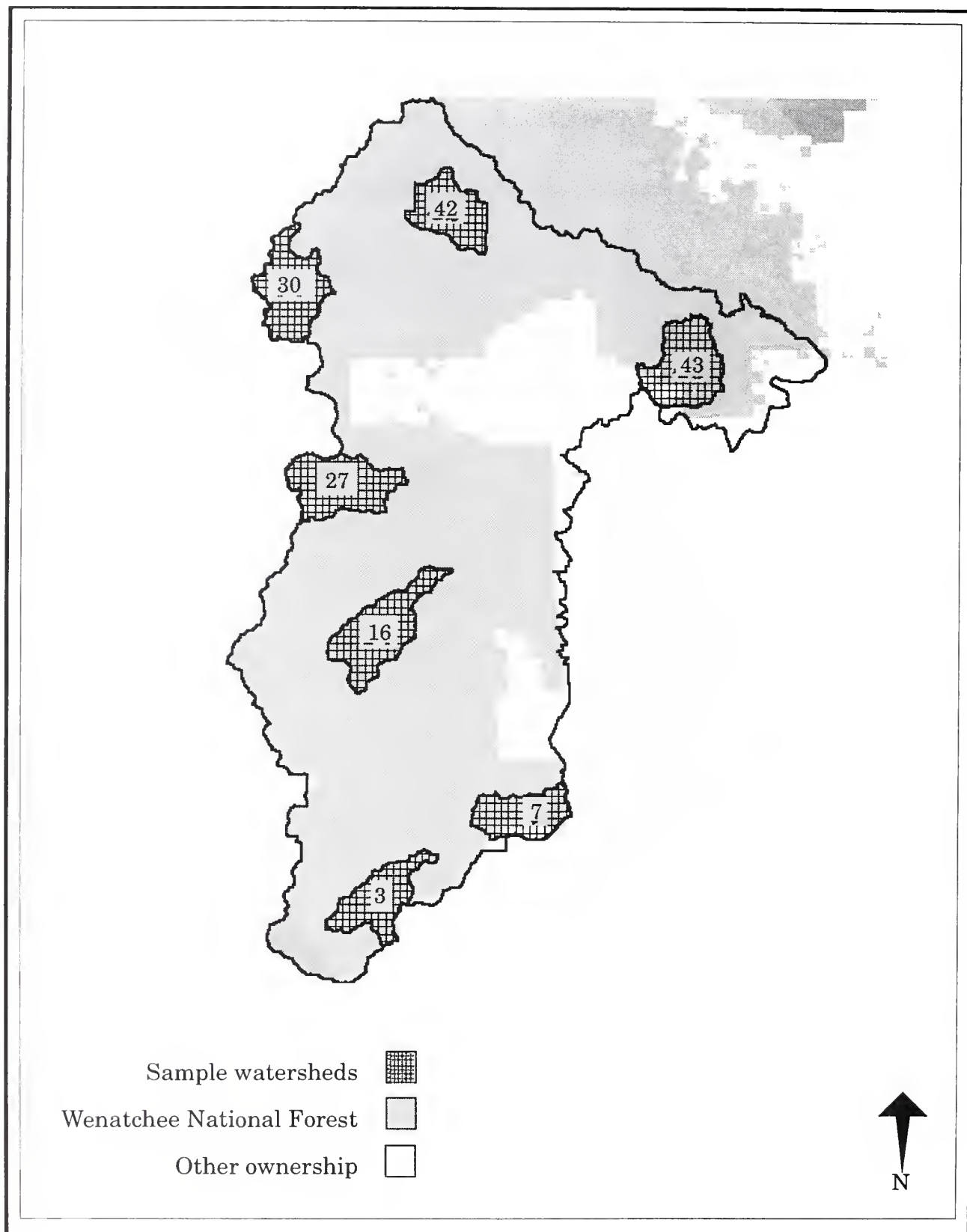


Figure 10—Watersheds on National Forest and other ownerships sampled for the eastside forest ecosystem health assessment in the Yakima River basin, Washington, 1993.

Project personnel contacted National Forests, the Pacific Northwest Forest Service Regional Office, and other agencies to determine what data were available that met our criteria. We had hoped to use the National Forests' Pacific Meridian (PMR) vegetation data base to assess current vegetation conditions; however, PMR data were available for only one Forest and their accuracy were not yet verified. However, current vegetation maps based on aerial photo interpretation that met our criteria were available for the Colville, Wallowa-Whitman, and Umatilla National Forests. We used these data for assessing current vegetation on a portion of the Pend Oreille River basin and all of the Grande Ronde basin.

Maps showing current vegetation for the other four river basins on the Okanogan, Wenatchee, and Deschutes National Forests either did not exist for the entire Forest, were not current, were not consistent with our mapping standards, or varied in vegetation mapping criteria. These sources were not suitable for our assessment, so we assembled mapping teams of National Forest personnel to create current vegetation maps by using recent aerial photography and orthophotographs.

We had intended to map historical vegetation from archived aerial photographs taken during the 1930s and 1940s. We found photographs of that vintage for many of the sample watersheds, but we had to use some 1950-era photographs in a few watersheds where earlier photography was unavailable (table 1). High-quality timber-type maps from that same period were being digitized by the Forest Service Geomtronics group in Portland, and we investigated using them to save time and money. We decided not to use the timber-type maps for several reasons: vegetation units were delineated by species and stand structure on the basis of commercial timber types and stand structure important for timber production, not by ecological criteria; stand attributes did not include sufficient information on stand structure important to forest health issues (for example, multiple canopy layers); we would have to map current vegetation under the same inappropriate criteria or map by our preferred attributes and then contend with historical and current vegetation mapped by different criteria; maps were done by counties during different years and possibly different mapping criteria, thus making the assembly and edge matching of county maps to create watershed maps difficult; and digitized maps for all the river basins would not be available until the summer of 1993.

In light of these difficulties, teams that were mapping current vegetation also mapped historical vegetation. Using teams would yield high-quality data that were timely and consistent across the temporal and spatial scales of analysis. We were not able to field-verify maps, so photo interpreters with field experience and expert knowledge of local conditions were assigned to teams. Without field verification, maps were to be used only for research associated with this assessment and not for management activities such as forest or project planning. Recent stand exams were used to validate photo interpretation when exams were available.

Quality control of map data was a high priority. We held a two day workshop with mapping crews to standardize criteria for delineating vegetation patches, clarify mapping procedures, and other data collection and submission procedures. Two skilled photo-interpreters visited each mapping crew weekly during the first month of mapping to ensure consistent, high-quality results from all crews. Crew members on each Forest were assigned to map both current and historical vegetation of a particular watershed to minimize variability associated with using several photo-interpreters.

Vegetation was mapped as distinct patches not less than 4 ha, delineated on the basis of homogeneity of vegetation composition and structure. The standard procedure for mapping vegetation was first to delineate patches on aerial photographs with the aid of a stereoscope, and then to transfer the mapped polygons to mylar overlays on geo-referenced orthophotographs. Manuscripting rules for map preparation were established to ensure consistent high-quality maps. Mylar map quads of sample watersheds were digitally scanned, edited, and edge-matched by using the LT+ software, and then entered into the ARC/INFO geographic information system (GIS) software. Composition and structural attributes of vegetation patches (table 2) were interpreted from stereo-photo interpretations and recorded on forms for entry as separate data files that were later merged with the digitized maps in GIS.

Table 1—Dates of historical and current aerial photography used to map vegetation pattern in 6 river basins in eastern Oregon and Washington for the eastside forest ecosystem health assessment

River basin	Watershed number	Historical photo year	Current photo year
Deschutes	4	1959	1991
	5	1959	1991
	13	1959	1991
	18	1959	1991
	30	1959	1991
	37	1959	1991
	38	1959	1991
	45	1943	1991
	47	1943	1991
	56	1943	1991
Grande Ronde	4	1938	1987
	13	1938	1987
	18	1948	1987
	21	1948	1987
	35	1955	1987
	40	1955	1987
	41	1955	1987
	45	1938	1987
	52	1938	1987
Methow	3	1956	1992
	9	1954	1992
	11	1956	1992
	15	1955	1992
	26	1956	1992
	38	1955	1981
	41	1956	1992
	42	1956	1992
	49	1956	1981
Pend Oreille	55	1956	1981
	3	1935	1985
	5	1935	1985
	9	1935	1985
	13	1932	1985
	17	1955	1985
	24	1934	1986
Wenatchee	All	1949	1992
Yakima	3	1949	1992
	7	1949	1992
	16	1949	1992
	27	1949	1992
	30	1949	1992
	42	1955	1992
	43	1942	1992

Table 2—Attributes of forest and nonforest stands interpreted from aerial photographs for the eastside forest ecosystem health assessment of eastern Oregon and Washington, 1993.

Nonforest type: A vegetation patch was considered nonforested when total canopy closure was <10-percent. Categories were: rock, water, wet meadow or marsh, alpine meadow, dry meadow or grassland, grass/forb after logging, shrub, bare ground (burned or logged), bare ground (slumps erosion), agriculture, and urban.

Overstory and understory species: Dominant overstory and understory species were recorded. Species were later grouped to maximize reliability of photo interpretation and to minimize the number of codes by grouping uncommon species or species with similar shade-tolerance.

The primary overstory species or species groups were ponderosa pine, western larch, lodgepole pine, Douglas-fir, grand fir/white fir, Pacific silver fir, subalpine fir/Engelmann spruce, western hemlock/western redcedar, mountain hemlock, whitebark pine/subalpine larch, western white pine/sugar pine, hardwoods, or juniper.

Primary understory species and groups were ponderosa pine, western larch/ lodgepole pine, Douglas-fir/ grand fir/white fir/Pacific silver fir, western hemlock/western red cedar, mountain hemlock, subalpine fir/Engelmann spruce, whitebark pine/subalpine larch, hardwoods, juniper, grass/forb, shrub, and bare ground.

Overstory and understory tree size classes: Trees sizes were estimated as: seedling and saplings (<13 cm [<5 in] d.b.h.); poles (13-23 cm [5-8.9 in] d.b.h.); small sawtimber (24-41 cm [9-15.9 in] d.b.h.); medium to large sawtimber (41-64 cm [16-25 in] d.b.h.); and mature to overmature sawtimber (>64 cm [25 in] d.b.h.).

Total canopy closure and overstory canopy closure: Closure was estimated to the nearest 10-percent

Canopy layers: Estimated as 1, 2, or >2 layers.

Tree density: Density was not estimated from aerial photographs, but was recorded from field data (stocking surveys, timber stand exams) where available.

Clumpiness: Horizontal patchiness of overstory tree cover. Stands were rated as: (1) Clumpy - yes or no; (2) If clumpy, clump distribution is widely scattered, moderately dense, or dense; and (3) average clump size is <0.4 ha (1 acre), 0.4-2 ha (1-5 acres), or >2 ha (5 acres) but <4 ha (10 acres).

Crown differentiation: Degree of differentiation among overstory tree crowns. Estimated as low (<30-percent difference), medium (30-100-percent difference), or high (>100-percent difference).

Riparian or wetland: Indicated whether the polygon was riparian or wetland; used with overstory vegetation to estimate forested and nonforested wetland area.

Logging entry: Visible logging was interpreted as no logging apparent, regeneration harvested (clearcut, shelterwood, seedtree), selection harvested (partial cut, selective harvest), thinned (commercial or pre-commercial), or patch clearcut (clearcut patches were <4 ha (10 acres). If patch clearcut, we estimated the percentage of the stand area in clearcut patches to the nearest 10-percent.

Dead trees and snags: Dead tree and snag abundance was estimated as none apparent, <10% of trees dead, 10 to 39-percent of trees dead, 40 to 70-percent trees dead, and >70-percent trees dead.

Vegetation and Landscape Pattern Analysis

Vegetation maps and patch attributes derived by photo-interpretation formed the basic data set from which all subsequent analyses were done. Patches were described by attributes of composition and structure, and grouped by vegetation types developed from overstory species composition and stand structural classes. Structural classes were defined as:

seedling-sapling-pole (SSP)—one canopy layer, seedling, sapling, or pole trees (< 23 cm diameter at breast height [d.b.h.]);

young—two canopy layers, overstory pole or young trees (13-40 cm d.b.h.), understory seedlings, saplings, or poles (< 23 cm d.b.h.);

mature—≥ two canopy layers, overstory mature trees (41-64 cm d.b.h.), understory trees young or smaller (< 40 cm d.b.h.);

mature parklike—one or two canopy layers, mature to old overstory trees (> 40 cm d.b.h.), understory trees absent or saplings (< 13 cm d.b.h.);

old forest—≥ two canopy layers, overstory trees larger than mature (> 64 cm d.b.h.), pole to mature understory (13-64 cm d.b.h.).

We used the percentage area in various classes of categorical attributes (that is, the percentage of the watershed with Douglas-fir overstory, mature structure class, dead tree category, and so on) and the mean watershed value of continuous variables to describe historical and current conditions in a watershed. The change from historical to current conditions in a watershed was estimated as the difference between historical and current values, not as the percentage change from historical conditions. Means, standard errors of the means, and confidence intervals of variables for river basins were estimated by using methods for stratified random sampling (Cochran 1977) with watershed sample units. Significant ($P \leq 0.10$) change from historical to current conditions was determined by examining the 90-percent confidence interval around the mean difference for the river basin, which was estimated as the stratified random mean from pair-wise comparisons of watersheds. If the confidence interval included zero, no significant change was recorded.

We used the basic data set to examine changes in landscape composition and stand structure. We analyzed changes in landscape diversity and pattern by estimating size, density, and shape attributes of vegetation-type patches and indices of vegetation pattern. Indices were estimated for whole watersheds from raster versions of the vector ARC/INFO maps. Grid size in the raster-based pattern analyses was 1 ha. We used the DISPLAY program (Flather 1993) to calculate indices of diversity (Shannon-Weiner H'), dominance, and contagion (point diversity) on the scale of 1 ha (O'Neill and others 1988). The perimeter-area fractal index of patch shape complexity (O'Neill and others 1988) was estimated by regression techniques (Burrough 1986).

Insect and Disease Hazard Analysis

Major forest insect and disease hazards were evaluated for historical and current conditions in each watershed. Insect and disease hazard did not equate to actual occurrence because we did not do inventories. Rather, "hazard" indicated presence of susceptible host vegetation in susceptible arrangements. Insects and diseases were grouped into 12 categories for assessment. The two principal defoliators, the western spruce budworm and the Douglas-fir tussock moth, were combined to estimate a defoliator hazard rating, although the hazard variables used were most appropriate to the western spruce budworm. Hazard associated with bark beetles was assessed separately for the Douglas-fir beetle, western pine beetle, mountain pine beetle, and fir engraver. Western pine beetle hazards were type 1, hazard to mature and overmature ponderosa pine; and type 2, hazard to immature and overstocked ponderosa pine. Mountain pine beetle hazards were type 1, hazard to overstocked lodgepole pine; and type 2, hazard to immature and overstocked ponderosa pine. Dwarf mistletoe hazards were computed for mistletoes of western larch,

Douglas-fir, ponderosa pine, and lodgepole pine. Root diseases were combined for a group hazard rating. Diseases included were laminated root rot, *Armillaria* root disease, and S-group annosum root disease. P-group annosum root disease hazard was not evaluated.

The basic procedure was to rate hazard associated with each insect or pathogen species (or group) for each forest and nonforest polygon as the sum of scores for 4 to 6 hazard variables. Site quality, a hazard variable used in all calculations, was based on the presence of host species in the overstory and understory. Host abundance, another hazard variable, was calculated by computing overstory and understory crown cover in host species. Canopy structure was factored into polygon ratings by considering the number of canopy layers and their composition. Stand density was estimated qualitatively from total canopy cover. For some beetle species, crown differentiation was an additional surrogate variable for stand density. Host age was approximated from overstory and understory size-class data. A detailed description of all procedures is in appendix A.

Continuity of host species in entire watersheds was estimated using the DISPLAY pattern-analysis software to determine host-host transition frequencies at the scale of 1 ha. The host-host transition frequency measured the number of times host cells were next to other host cells. The frequency was divided by the total number of transitions to yield an index of host species continuity ranging from 0 to 1. The index incorporated the total area and the spatial juxtaposition or fragmentation of host species area (Turner 1990). Small index values indicated a combination of low area or high fragmentation of host species patches, and high values indicated large, contiguous patches of host species. A value of 1 indicated 100 percent cover by host species.

We used some or all of these variables to rate hazard associated with each of the 12 species or species groups in each watershed and basin. Polygon scores for each variable were summed by species then weighted by the proportion of watershed area occupied by the polygon. A watershed score for each species was computed by summing the weighted polygon scores then adding the host species continuity score, if applicable.

Fuel Loading and Fire Behavior

We used published information to calculate ground fuel loadings and surface fire behavior characteristics for each polygon in the sample watersheds. Photo-interpreted attributes of polygons were matched to the closest situation represented in one of several fuel and fire behavior photo series (Fischer 1981, Maxwell and Ward 1976, Maxwell and Ward 1980) by developing a key based on vegetation composition and structure. Of the fuel and fire behavior photo series available, 36 photos were selected or stylized to represent the range of fuel conditions within the six river basins. These photos were applied to fuel complexes representing nonforested conditions, natural forested conditions, and conditions created after logging, thinning, and other management activities. A more diverse array of fuel photo series could have been selected if information about stand density, applicable understory characteristics, or further details of management activities had been described for each polygon.

For each fuel and fire behavior photo series, we used information on fuel loadings by size class, rate of spread (ROS), flame length (FL), and resistance to suppression (RTS) to develop the fuel loading and fire behavior data base. Fires can be classified into three general categories of intensity: surface, understory, and crown fires (Agee 1993). Our approach to evaluate fire behavior covers surface and understory fires only. Crown fire potential will be addressed in a later assessment; however, predicting crown fire behavior is a difficult problem, and estimation techniques are still being developed (Rothermel 1991). Resistance to suppression, a subjective assessment of the time it takes to construct firelines under different fuel conditions, was examined to supplement the fire behavior information. RTS estimated as the time needed to construct a line that holds a fire, is difficult to measure. Estimates taken from the fuel and fire behavior photo series are based on field experiences but would vary further depending on crew skill and terrain.

The only factor influencing ROS and FL that varied among polygons was the fuel complex. We based estimates of ROS and FL described for each fuel complex in the photo series on constant conditions of zero percent slope, 6.5 km/hour (4 miles/hour) mid-flame wind, and 4 percent fuel moisture. Slope characteristics and other geographic features that strongly influence fire behavior were not described for the individual polygons during the data collection. These characteristics can be added in subsequent analyses.

Because attributes useful for matching polygons to fuels and fire behavior photos, such as stand densities, were not available, other attributes were used. We used the vegetation type developed for this assessment as the primary attribute to develop a fuels key for unmanaged (that is, not recently logged) polygons because it incorporates several stand characteristics. Some vegetation types were keyed individually; where it was assumed fuels and fire behavior would be similar, vegetation types were grouped. When vegetation type was not distinct enough to assign fuels or fire behavior, additional attributes (such as overstory crown closure) were used. Some nonforest types were keyed directly, without reference to vegetation type.

For managed (that is, recently logged) polygons, vegetation type was not used in the key. Because information was limited, we assumed that fuels and fire behavior would be relatively consistent across vegetation types within each class of logging activity. To differentiate within each activity category, we used available stand structure attributes (number of canopy layers and crown closure).

The photos selected from the natural fuels photo series (Maxwell and Ward 1980) to represent the unmanaged polygons provided all necessary fuel loading and fire behavior information. The photos selected to represent the managed polygons were, in all but two cases, taken from a photo series depicting activity fuels (Maxwell and Ward 1976), because it provided all fuel loading information. We took fire behavior information for these photos from Ward and Sandberg (1981). We used a photo from Fisher (1991) for two cases of managed polygons where no photo in Maxwell and Ward (1976) was applicable. The Fischer photo contributed fuel loading data and a National Fire Danger Rating System (NFDRS) fuel model. Fire behavior was taken from the fire behavior fuel model corollary to the given NFDRS fuel model (Anderson 1982). We assigned nonforested polygons fuel loading and fire behavior characteristics from any of the three photo series mentioned or stylized from those photos.

Polygons with slash fuels were recorded as bare ground, burned, or logged during watershed mapping. Under these conditions, a polygon was given a relatively low ROS and FL. No method or information was available to determine if activity fuels were treated in polygons where logging had occurred several years before the aerial photographs were taken. Fuels in these polygons were assumed to be untreated; they were matched to a fuel and fire behavior photo series of old logging slash according to the harvest management activity (for example, thinning, partial cut). Polygons with untreated activity fuels resulting from very recent tree harvesting could not be separated from older harvests, so they were given the same ROS and FL, even though recent, untreated activity fuels produce much higher ROS and FL, and present a hazardous fire management situation.

Maxwell and others (1983) designated a $ROS > 2.5$ m/min (7.6 chains/h), a flame length > 2.3 m (7.6 ft), or both as thresholds at which fire control becomes difficult during initial attack. Hence, conditions that exceed these thresholds are presented as high risk—that is, high potential for large and difficult-to-control wildfires. We used these thresholds as criteria for evaluating risk. Our assessment of risk should be considered preliminary, however, because important factors that influence fire behavior such as slope, wind speed, and moisture content of fuels were held constant throughout this study.

The stratified sampling procedure to select sample watersheds and determine patterns at the river basin scale also applies to all aspects of the fire-related analyses. Product-moment correlation coefficients were calculated to estimate covariation of ROS and FL with the proportion of area logged in a given sample watershed. The association between ROS and FL with proportion of area logged by harvest technique (for example, clearcut, thinning) was examined individually by the same correlation methods.

Smoke Production

Emissions inventory approach—Following the emissions inventory approach described by Peterson (1988), we determined fuel loading for sample watersheds by the previously described methods. Historical, current, and future areas burned in prescribed fires and wildfires were estimated from smoke management reports, surveys, and wildfire data bases. We used estimated fuel moisture value and available fuel consumption models for the Pacific Northwest to calculate potential fuel consumption on a per hectare basis. Potential smoke production was estimated by multiplying fuel consumption by an assigned emission factor.

Area burned from prescribed fires and wildfires—The area recently burned by prescribed fires were determined from smoke-management reports for the years 1990 and 1991 (Stender, unpublished data; Ziolkko, unpublished data). Location and size of the burns were tallied for each sample watershed based on these reports. A literature review, surveys with Ranger District fuel-management officers, and discussions with researchers were used to determine historical and future prescribed burning occurrence.

We determined current wildfire occurrence from USDA Forest Service Region 6 fire data for 1970 to 1988. The areas burned during wildfires were obtained from electronic records stored at the National Interagency Fire Management Integrated Database, housed at the U.S. Department of Agriculture, Computer Center, Kansas City, Kansas. These records include the fire size and locations that determined which fires burned in sample watersheds within certain river basins. Historical wildfire data for the period before 1970 was not used in this analysis; however, electronic records for 1950 to 1970 are in a separate data base and could be used in a future analysis.

Fuel moisture—An average fuel moisture content was applied for prescribed fires and wildfires. This variable is important for calculating fuel consumption. Because most wildfires occur during the summer months, an average large-fuel moisture content of 20 percent was assumed. Most prescribed fires are conducted under cool and moist spring-like conditions (Ottmar and others 1990); therefore, an average large-fuel moisture content of 40 percent was assumed.

Fuel consumption—Fuel loading and fuel moisture content were entered into the CONSUME software (Ottmar and others 1993) to estimate potential fuel consumption per ha. CONSUME calculates fuel consumption by using the latest fuel consumption algorithms for the Pacific Northwest.

Emission factors and emission production—Fuel consumed (megagrams/ha) multiplied by an emission factor (g/kg) determines emissions production (kg/ha). We assigned a fire-average emission factor that corresponded to each set of fuels and fire behavior data. Emissions factors were expressed as grams of particulate matter less than 10 micrometers in size (PM10) emitted per kg of fuel consumed. Forested polygons were associated with one of four Pacific Northwest forest types for which emission factors were available: Douglas-fir/hemlock, ponderosa pine/lodgepole pine, mixed conifers, or hardwoods (Ward and others 1989). Emission factors ranged from 12.5 g/kg to 10.2 g/kg. Polygons dominated by shrubs were assigned the emission factor of 10.6 g/kg for chaparral (Hardy and Teesdale 1992) or sagebrush (Hardy and Teesdale 1991). Polygons dominated by grass were assigned the emission factor of 10 g/kg for grass (U.S. Environmental Protection Agency 1991). All logged stands were assigned an emission factor of 11.5 g/kg, which is the factor that comes closest to being the average of the four Pacific Northwest forest types (Ward and others 1989).

We used emission factors to estimate potential emissions per ha that could have occurred or might occur from historical or current prescribed burning. Emission factors for wildfire must be estimated when making comparisons with emissions from prescribed fires. Hardy and others (1992) calculated an average PM10 emission factor for a wildfire of 14.9 g/kg. We divided this factor by the prescribed fire emission factor for Douglas-fir/hemlock (the fuel type closest to that of the wildfire) to calculate a ratio. The ratio was then applied to each prescribed fire emission factor, except grass and shrub vegetation types, to determine a wildfire emission factor. The fuel consumed was multiplied by an appropriate emission factor to determine emissions produced from prescribed fire and wildfires.

All the polygons within a watershed were combined to obtain a mean value for the fire and smoke-related attributes. To compensate for differences in polygon sizes, a weighted mean was used (Hoshmand 1988). Hence, the contribution of a polygon to the watershed mean value is proportional to its size. Maps of three sample watersheds were produced to illustrate the watershed-scale patterns of fuel loading, potential fire behavior, and emission production during historical and current periods.

Mean values for the watersheds were obtained for the following variables: forest fuels (mg/ha); fuel consumption (mg/ha) in prescribed and wildfire scenarios; fire rate of spread (m/h); flame length (m); fire resistance to suppression (m/person-hour); smoke emission factors of PM10 (g/kg of fuel consumed); and smoke production of PM10 (kg/ha) for prescribed fire and wildfire. Once watershed mean values were obtained, the procedure to calculate the historical and current means for the river basin followed the stratified random estimation procedure.

RESULTS

Vegetation Change

Forest overstory composition—Several basins exhibited changes in total forest cover (fig. 11). Forest cover increased 8-percent ($P \leq 0.10$) during the past 50 years in the Deschutes and Grande Ronde basins, but decreased 6-percent ($P \leq 0.10$) in the Wenatchee drainage. An apparent 9-percent increase of forest area in the Pend Oreille drainage was not statistically significant; this was largely attributed to an increase from 29-percent forest cover in 1935 to 96-percent cover by 1985 in one watershed (watershed 5). This shift was accompanied by a like reduction in the area of bare ground in that watershed as vegetation recovered from a large fire.

No significant change was found in the area of forested and nonforested wetlands at the basin scale (fig. 11). A consistent trend, however, appeared in four of the basins, with 45 to 150-percent increases in forested wetland area from the past. Changes in watersheds were both positive and negative within a basin, however. About 30-percent of the sample watersheds exhibited a difference of 5 to 12-percent of total area in forested wetlands, with 40-percent of those watersheds showing declines, and 60-percent with increases in forested wetland area. Changes in nonforested wetlands were equally varied, with three basins exhibiting potential increases of 15 to 100-percent from historical area.

We found some dramatic shifts at the river basin scale in the composition of the forest overstory from early-successional species to more shade tolerant species (fig. 12a-c). Ponderosa pine decreased by 30-percent ($P \leq 0.10$) from historical cover in the Methow basin. Compensating increases in the cover of other species were not significant, but an apparent 26-percent increase in Douglas-fir cover probably accounted for most of the change. The greatest reduction (20-50-percent) in ponderosa pine cover occurred in the dry southwestern portions of the basin, in watersheds 3, 9, and 11. Watershed 3 was unique in also displaying a 450-percent increase in Douglas-fir overstory, an 84-percent decline in lodgepole pine cover, and a 43-percent decline in ponderosa pine cover.

The Pend Oreille basin exhibited a clear shift away from early-successional ponderosa pine, western larch, and western white pine, with 53-percent increases ($P \leq 0.10$) in Douglas-fir and western hemlock cover (fig. 12a-c). Watersheds on the southern and southwestern part of the basin (watersheds 5, 9, 13) displayed large (40 to 200-percent) increases in Douglas-fir cover. Increasing cover of late-successional western hemlock was evident in three watersheds. Watersheds 3, 9, and 24 exhibited 400 to 4000-percent increases in total western hemlock cover, affecting up to 29-percent of total watershed areas. Watershed 9 had a nearly complete loss (-99-percent) of western white pine cover. Watershed 5 was also unique in exhibiting a 96-percent decline in bare ground after fire recovery that was partially accounted for by 5300-percent and 100-percent increases in early-successional lodgepole pine and western larch cover, respectively.

At the basin scale the Deschutes river basin displayed little significant change in overstory cover except for a 45-percent decrease ($P \leq 0.10$) in bare ground (fig. 12a-c), and the 8-percent increase in forest cover noted earlier. At the watershed scale, the greatest overstory change occurred in the three watersheds (45, 47, 56) east of the Deschutes River on the dry Fort Rock District. Forest cover increased 45 to 80-percent, ponderosa pine overstory area increased 35 to 400-percent, and bare ground decreased about 30-percent from historical values. The two northerly watersheds (4, 5) east of the Mount Jefferson Wilderness exhibited change opposite from the southeastern Fort Rock watersheds. Ponderosa pine area decreased there by 45 to 60-percent, and Douglas-fir area increased 10 to 17-percent, as did grass/forb cover.

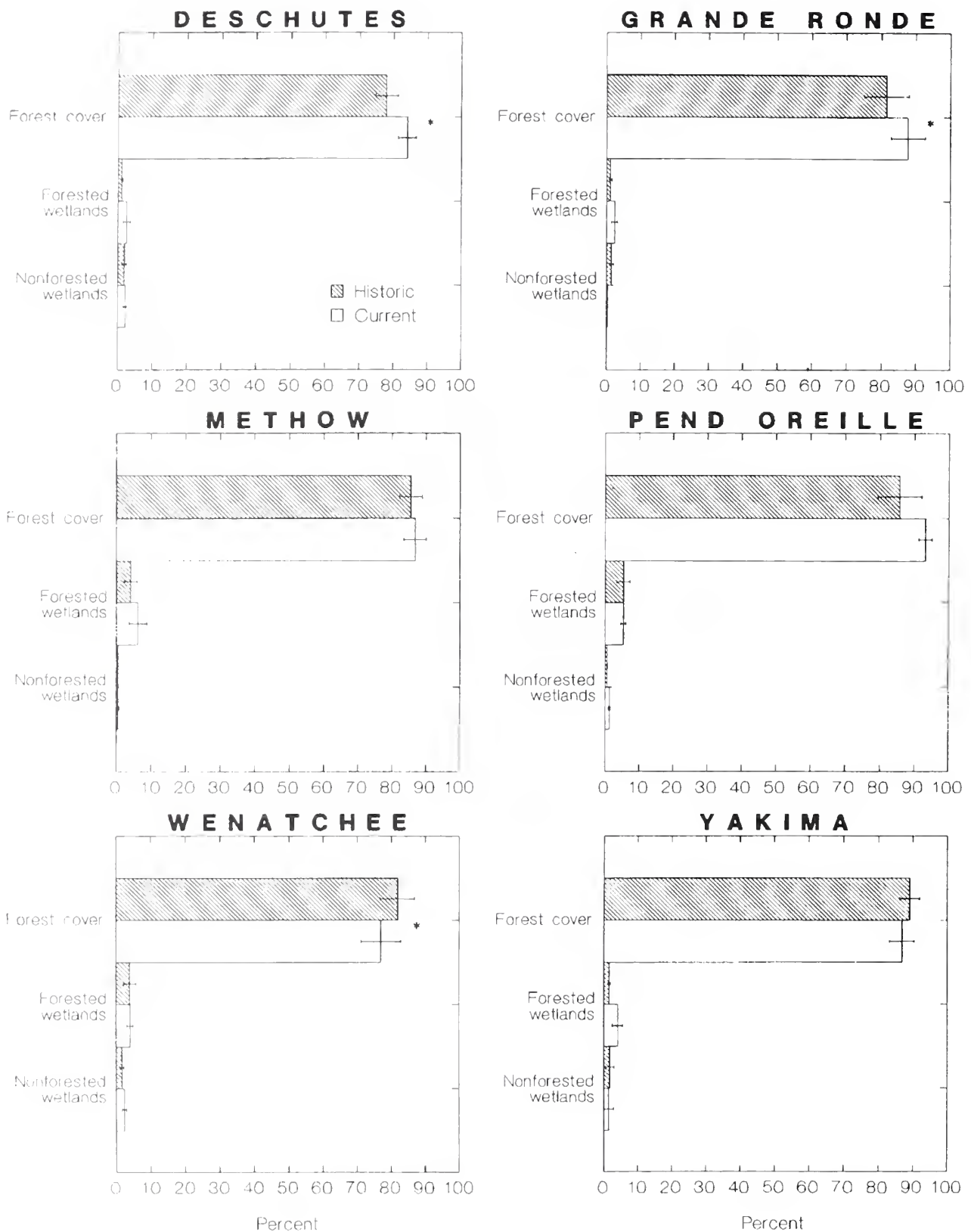


Figure 11—Historical and current forest cover, forested wetlands, and nonforested wetland area expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

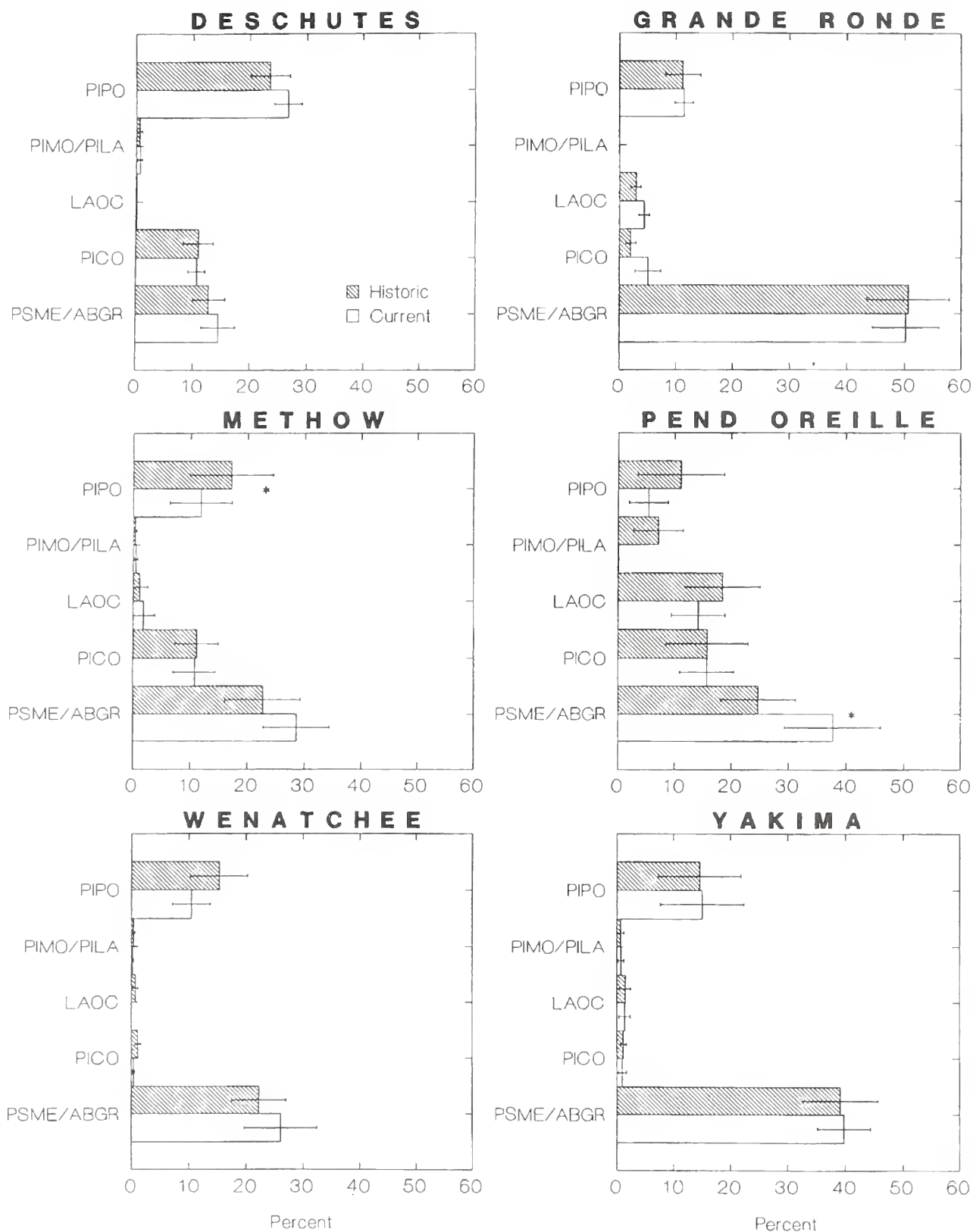


Figure 12a—Historical and current cover by overstory dominant tree species and nonforested vegetation expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions. Species codes: PIPO = ponderosa pine; PIMO/PILA = western white pine or sugar pine; LAOC = western larch; PICO = lodgepole pine; PSME/ABGR = Douglas-fir, grand fir, or white fir.

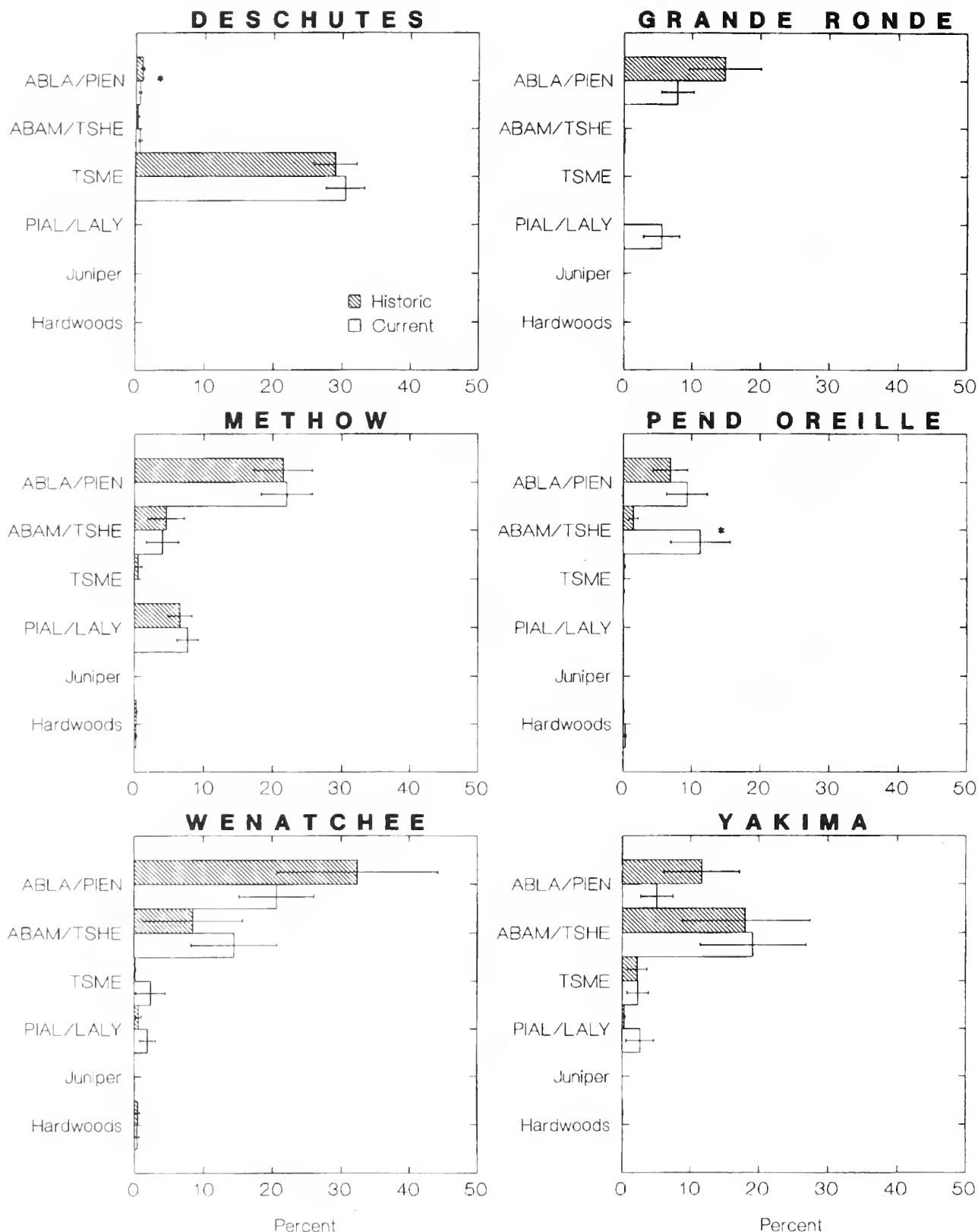


Figure 12b—Historical and current cover by overstory dominant tree species and nonforested vegetation expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions. Species codes: ABLA/PIEN = subalpine fir or Engelmann spruce; ABAM/TSHE = Pacific silver fir, western hemlock, noble fir, Shasta red fir, or western redcedar; TSME = mountain hemlock; PIAL/LALY = whitebark pine or subalpine larch.

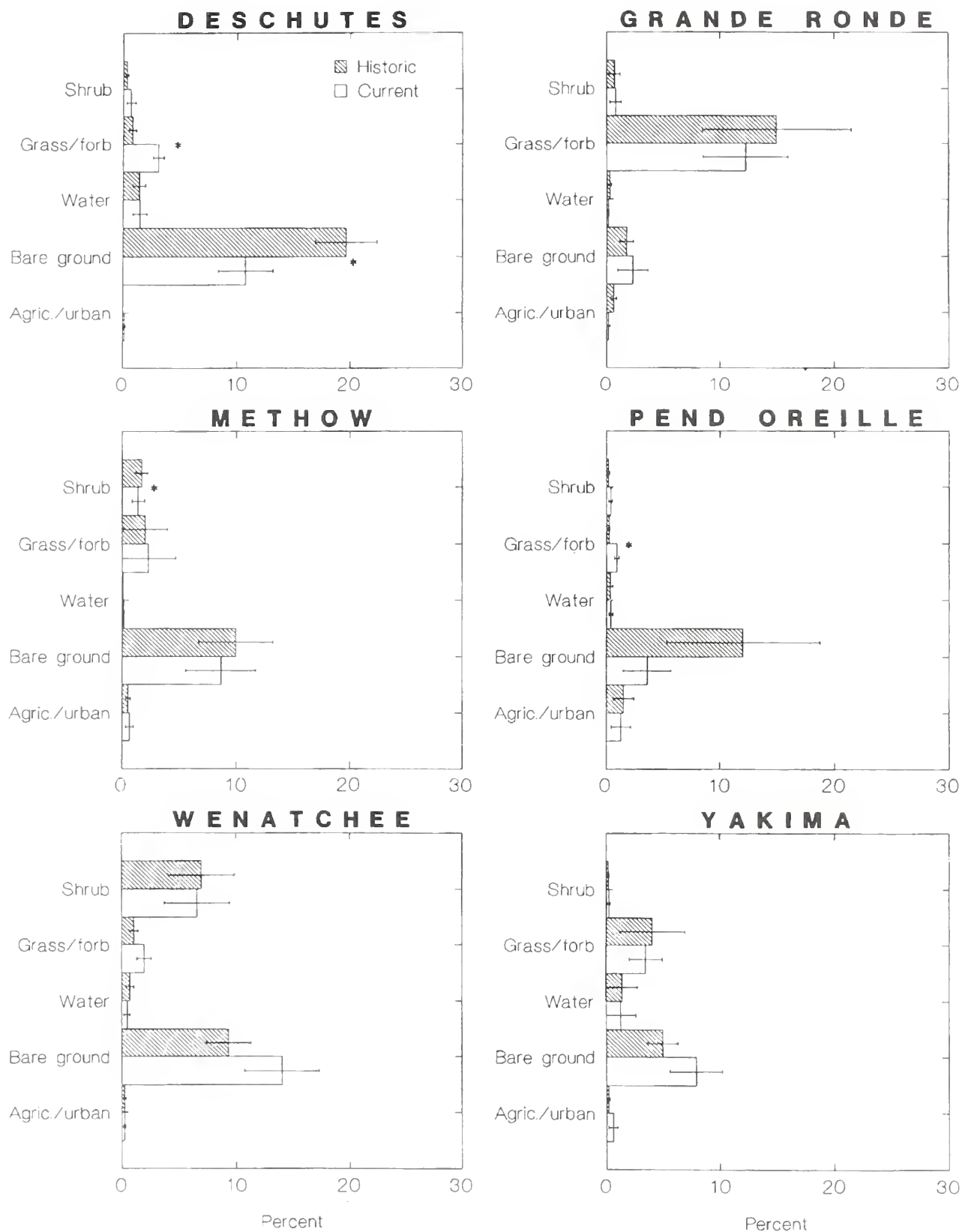


Figure 12c—Historical and current cover by overstory dominant tree species and nonforested vegetation as a percentage of total area on National Forest lands in river basins of eastern Oregon and Washington. Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P < 0.10$) between historical and current basin conditions.

Basin-scale changes in overstory cover were not significant in the Grande Ronde (fig. 12a-c) because large changes in watersheds were both positive and negative. Three watersheds (45, 52, 55) in the northern part of the drainage on the Umatilla National Forest portion of the basin exhibited a 90-percent decrease in early-successional ponderosa pine cover and a corresponding 35 to 230-percent increases in Douglas-fir cover. Western larch cover in these watersheds also declined 80 to 100-percent.

Watersheds west of La Grande followed an opposite path with increasing area of early-successional species. Douglas-fir cover decreased 10 to 45-percent in five watersheds (4, 13, 18, 21, 41). Ponderosa pine cover concurrently increased up to 100-percent to account for 5 to 30-percent of the total watershed area in two watersheds (13, 21), and lodgepole pine increased 300-percent in another watershed (4). The shift in composition from Douglas-fir to ponderosa pine in watershed 21 was accompanied by a 32-percent decrease in grass understories from 59 to 40-percent of total area.

Watersheds in the Eagle Cap Wilderness changed uniquely. Two watersheds (35, 40) exhibited 40 to 60-percent declines in historical subalpine fir cover and increases in white-bark pine area from 0 to 22 to 36-percent of total area. This change may have been a result of large fires in the 1980s.

The Wenatchee River basin exhibited no significant basin-wide change in overstory composition, because change in watersheds was highly variable. Two watersheds (16, 35) in managed forest areas had 30 to 40-percent reductions in ponderosa pine cover with concurrent increase of 30 to 50-percent in Douglas-fir. Two of the three wilderness watersheds (6, 18) changed very little in overstory composition from historical conditions.

Changes in the Yakima basin were negligible at the basin scale, but varied at the watershed scale. Four of the seven watersheds exhibited decreases in Douglas-fir and Pacific silver fir cover of 10 to 60-percent.

Understory composition and stand structure—We found substantial basin-wide shifts in understory composition and stand structure from open to closed stands in the Grande Ronde and Pend Oreille basins (figs. 13a-b, 14). Open grass/forb and shrub understories decreased from 90 to 100-percent ($P \leq 0.10$) from historical values in the Grande Ronde. Ponderosa pine understory increased by over 1000-percent from historical conditions ($P \leq 0.10$), while shade-tolerant Douglas-fir/grand fir increased 24-percent ($P \leq 0.10$) and subalpine fir increased 100-percent. These changes were accompanied by a marked 325-percent increase ($P \leq 0.10$) in two-layered young stands accompanied by 60 to 90-percent reductions ($P \leq 0.10$) in seedling-sapling-pole (SSP), mature parklike, and old-forest stands. These structural changes occurred with all overstory species (appendix B). Overstory canopy closure declined by 22-percent ($P \leq 0.10$) at the same time that total canopy closure did not change (fig. 15), indicating an increase in understory cover and density. Stand density also increased horizontally as shown by changes in tree distribution within stands, or stand clumpiness. Tree distribution was more dense, less scattered, and occurred in larger clumps ($P \leq 0.10$) (fig. 16).

The composition of forest understory in the Pend Oreille also shifted markedly from early successional to late-successional shade-tolerant species. The area of western hemlock understory increased 250-percent ($P \leq 0.10$) from historical levels (fig. 13a-b). At higher elevations, the area in subalpine fir/Engelmann spruce understory increased nearly threefold ($P \leq 0.10$). Trends in the distribution of structural classes were not significant, but showed a decline in smaller size classes and increases in larger classes. Development of two-layered stands occurred primarily in the ponderosa pine, lodgepole pine, and subalpine fir types (appendix B), but there were slight increases in parklike stands in all these types. All structure classes of Douglas-fir/grand fir and western hemlock increased in area. Within-stand clumpiness, or horizontal patchiness, decreased, with stands becoming more densely clumped (fig. 16). Other structural changes in the Pend Oreille basin varied among watersheds, making basin-wide assessments difficult; however, the trend among watersheds was for successional advancement with reduction in area of early seedling-sapling-pole (SSP) seral stages and an increase in area of young and mature classes.

High variability among watersheds made detecting basin-wide shifts difficult, but increasing density, canopy layering, and tree size with successional advancement were evident. In two northern watersheds (3, 5) in the Deschutes basin, understory ponderosa pine declined by about 65-percent, but Douglas-fir increased 30 to 90-percent. In the eastern dry watersheds where Douglas-fir is largely absent, ponderosa pine in the understory increased dramatically from 100 to 4500-percent, while grass, shrubs, and bare understory conditions decreased. Along with these changes in understory, a shift occurred from SSP to two-layered mature forest ($P \leq 0.10$) (fig. 14). The SSP ponderosa pine stands declined 40-percent and two-layered young and mature stand area increased about 55-percent (appendix B). The area of two-layered mature lodgepole pine stands increased markedly from 0.02-percent of the watersheds to about 1-percent. Mountain hemlock stands advanced successional from young to mature classes, but also with an increase in parklike conditions. Infilling of canopy gaps and canopy layering was also indicated by the increasing density and differentiation of canopies as shown by greater stand clumpiness ($P \leq 0.10$) (fig. 15) with more dense and larger clumps ($P \leq 0.10$) (figs. 16, 17), and greater crown differentiation (fig. 18).

The primary understory change in the Methow basin was the loss of mature parklike and old-forest structural classes ($P \leq 0.10$) with an increase in young forest (fig. 14). Successional advance was indicated by a 28-percent increase ($P \leq 0.10$) in the area of stands with subalpine fir/Engelmann spruce understories (fig. 13a). Parklike and old stands of ponderosa pine decreased, and two-layered young stands increased (appendix B). Understory ponderosa pine increased by 350-percent in one low-elevation watershed at the south end of the basin (3), similar to trends in the Grande Ronde and Deschutes basins. Lodgepole pine stands also exhibited seral advancement with declines in the SSP stands and more two-layered young stands. Area of young and mature two-layered Douglas-fir/grand fir stands increased by 70-percent, and parklike and old stands declined 35 to 40-percent. The structure of Pacific silver fir/western hemlock stands exhibited a definite shift to old forest conditions. Increasing understory density was associated with apparent declines in shrub, hardwood, and grass understories (fig. 13b).

Structural change in the Wenatchee basin was shown by an 18-percent decline ($P \leq 0.10$) in young stands, with an apparent 26-percent increase in old forests (fig. 14). Early successional ponderosa pine and western larch understories decreased, Douglas-fir/grand fir/Pacific silver fir and western hemlock understories increased by 80 to 100-percent. In contrast to increasing development of understories, grass/forb understories increased from historical times in the Wenatchee basin ($P \leq 0.10$), most likely in association with increases in parklike ponderosa pine, Douglas-fir, Pacific silver fir, and mountain hemlock types (appendix B). Seral advance to mature and old stages was evident in Pacific silver fir, mountain hemlock, and white-bark pine/subalpine larch types.

Change in stand structure in the Yakima basin was characterized by a 50-percent increase in the SSP stage, an 80-percent reduction in old forest area, and a 79-percent increase in bare ground (fig. 14). Most of the decline in old and mature classes was in the ponderosa pine, Douglas-fir, and Pacific silver fir types (appendix B). These changes were the likely result of a 15-percent increase in logging activity, mainly clearcut logging (fig. 19). Development of forest understories and stand layering was indicated by large increases in the area of two-story young Douglas-fir, Pacific silver fir/western hemlock, and white-bark pine/subalpine larch stands (appendix B), and by an increase in highly differentiated crowns ($P \leq 0.10$) (fig. 18).

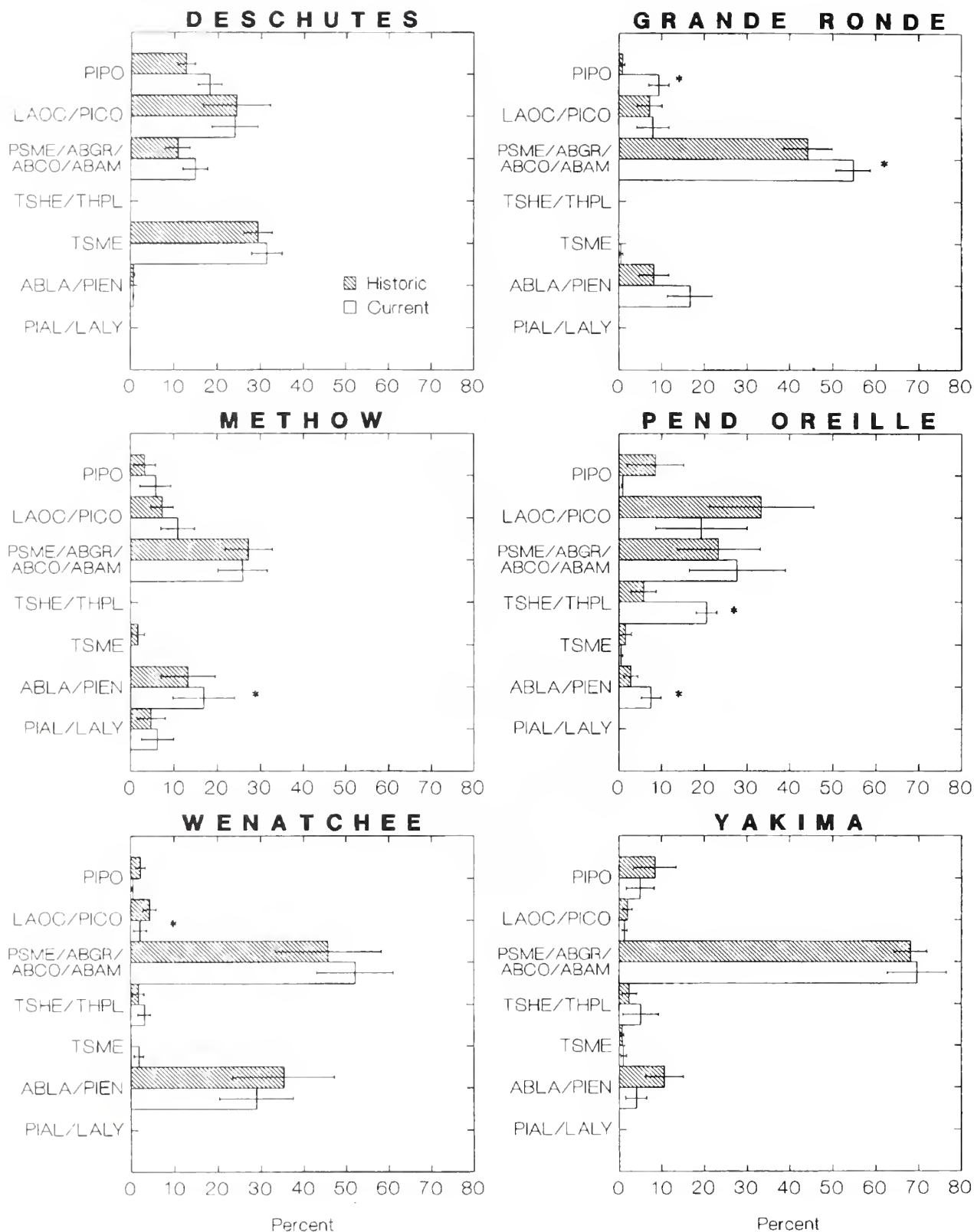


Figure 13a—Historical and current cover of understory tree species expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington. Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions. Species codes: PIPO = ponderosa pine, western white pine or sugar pine; LAOC/PICO = western larch or lodgepole pine; PSME/ABGR/ABCO/ABAM = Douglas-fir, grand fir, white fir, Pacific silver fir, noble fir, or Shasta red fir; TSHE/THPL = western hemlock or western redcedar; TSME = mountain hemlock; ABLA/PIEN = subalpine fir or Engelmann spruce; PIAL/LALY = whitebark pine or subalpine larch.

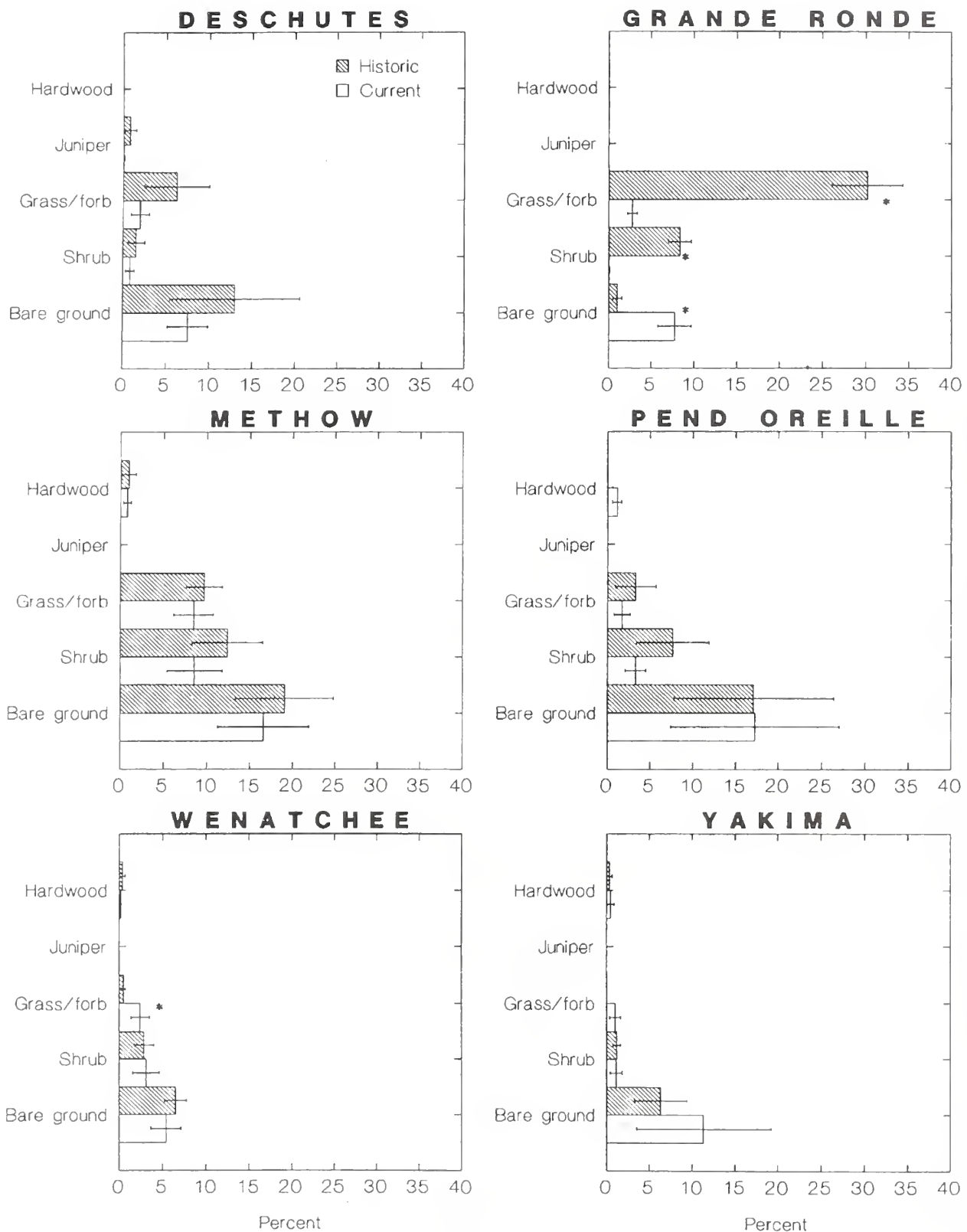


Figure 13b—Historical and current cover of understory tree species expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

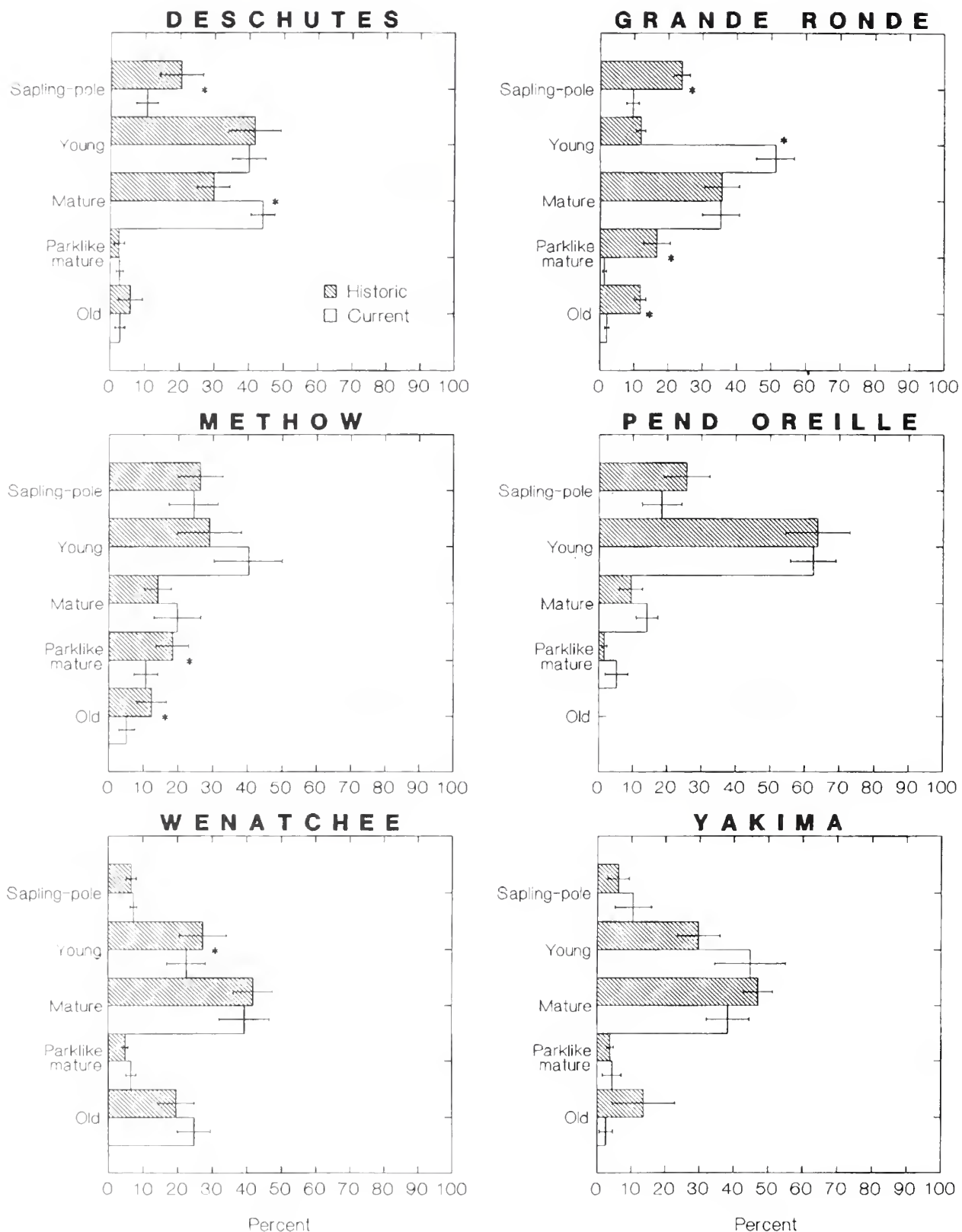


Figure 14—Historical and current stand structure expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington.
 Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between Historical and current basin conditions.

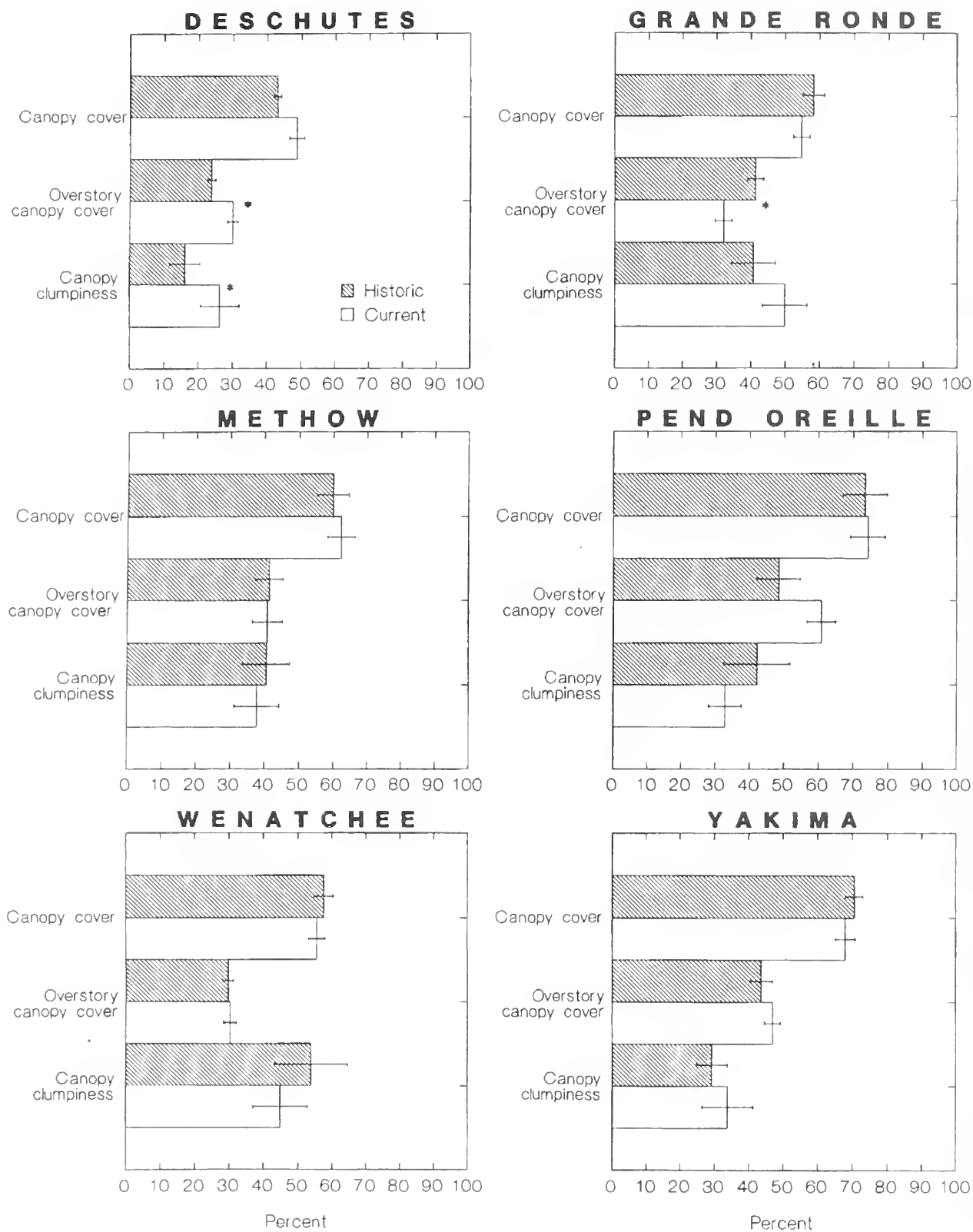


Figure 15—Historical and current total and overstory canopy closure, and clumpiness of forested stands expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

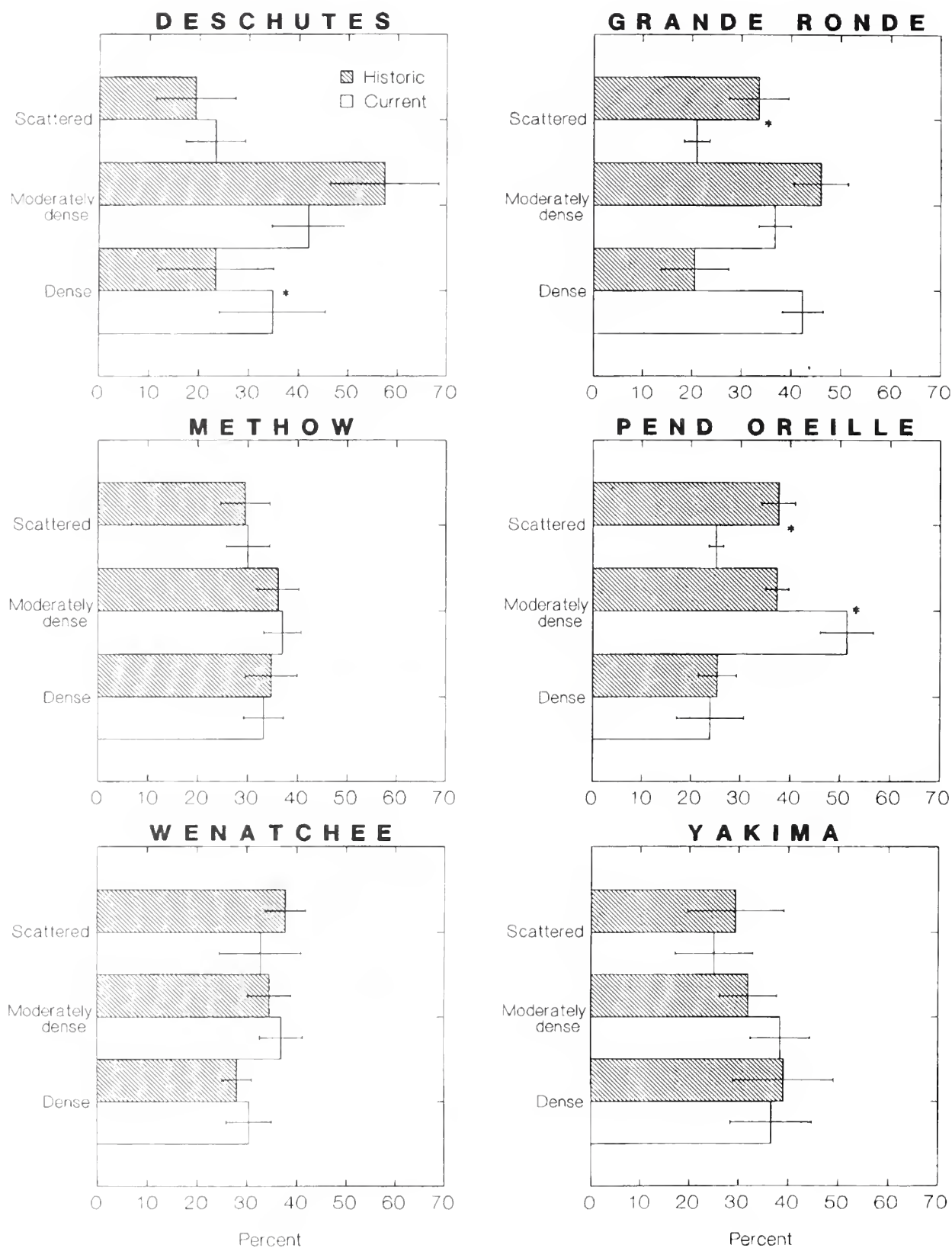


Figure 16—Historical and current clump distribution within clumpy forest stands expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

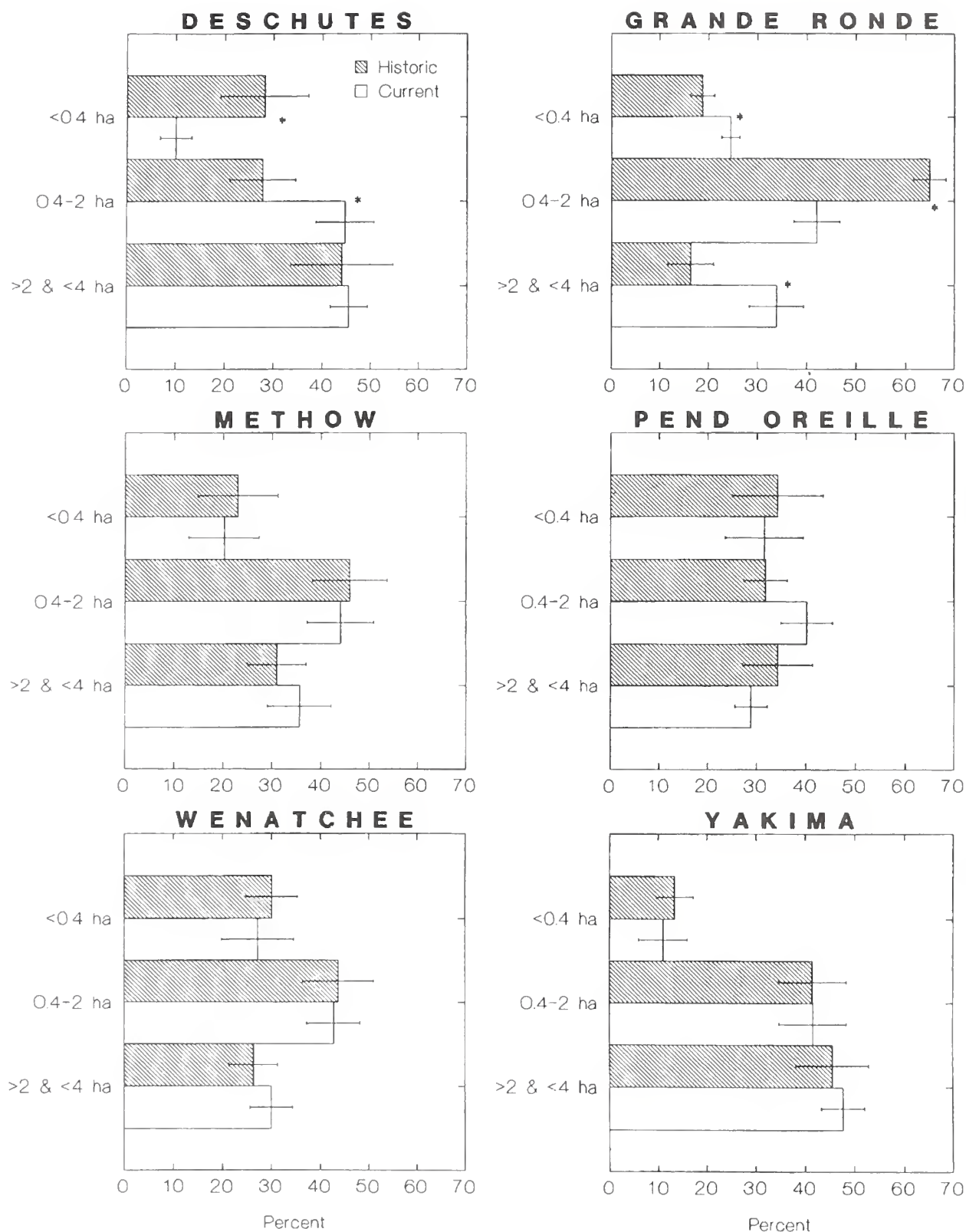


Figure 17—Historical and current clump size within clumpy forest stands expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington. Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

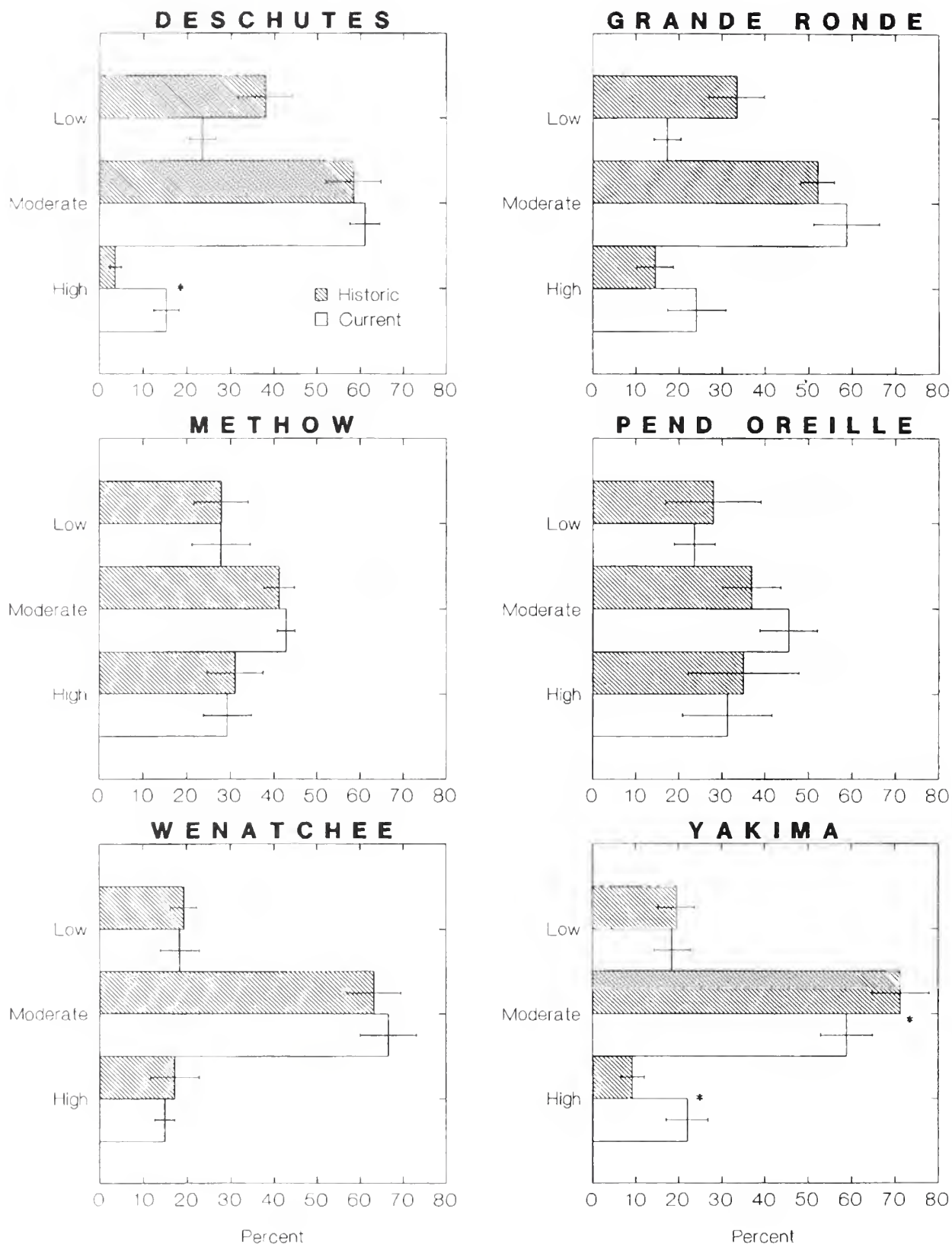


Figure 18—Historical and current crown differentiation of forest stands expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington. Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

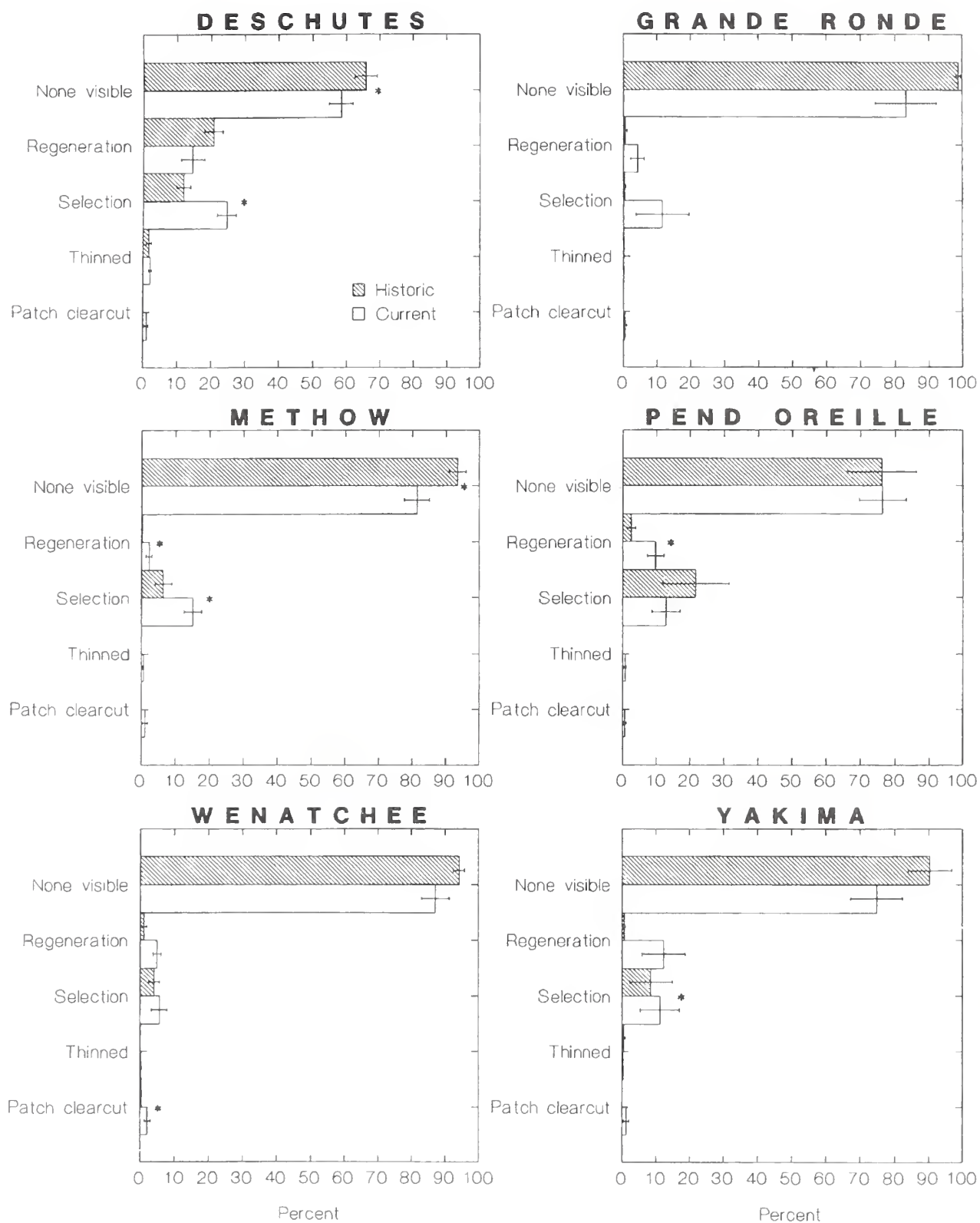


Figure 19—Historical and current logging activity expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington. Categories are: no historical visible logging, regeneration harvest, selection harvest, thinning, and patch clearcutting. Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

Dead trees—The percentage of dead trees increased in nearly all river basins (fig. 20). Two patterns were noted. High concentrations of dead trees (> 10 -percent dead) were mostly found in the Deschutes and Grande Ronde basins, but affected areas were less than 20-percent of the basin areas. In the Wenatchee and Yakima basins, dead trees were less concentrated within patches (< 10 -percent dead); but this condition was more widespread, however, and occurred in 40 to 50-percent of the basin areas. In the Deschutes basin, the area with some dead trees increased 19-percent, which was largely accounted for by a 1000-percent increase in severely affected stands (10-39-percent dead trees) ($P \leq 0.10$). In the Grande Ronde, the trend was for less area in the low mortality class (≤ 10 -percent dead), and a 1400-percent increase ($P \leq 0.10$) in stands that had 40 to 70-percent dead trees. Two exceptions were watersheds in the Eagle Cap Wilderness where large fires occurred in the 1980s. Those watersheds exhibited decreases in area with dead trees and a 28 to 58-percent increase in the area of stands with no dead trees. In the Wenatchee and Yakima basins, the area with 10-percent or fewer dead trees increased 40 to 55-percent.

Little basin-wide change in the occurrence and severity of dead trees was noted in the Methow basin (fig. 20) because watershed data were highly variable. Individual watersheds revealed several patterns of change. Two watersheds, one in wilderness (55) and one in managed forest (3), indicated 80 to 100-percent declines in dead tree classes and increases in unaffected area by 14 to 27-percent. One watershed (15) displayed a 35-percent increase in unaffected area, but a 1150-percent increase in area with 10 to 39-percent dead trees. In other Methow watersheds, the area of stands with up to 10-percent dead trees increased to occupy 2 to 40-percent of the watershed.

The change in dead tree abundances was also variable in the Pend Oreille basin, and no significant basin-wide changes were found. A basin-wide increase in unaffected and lightly affected stands was indicated, however (fig. 20). The area with no apparent mortality increased in four of the six watersheds from 10 to 7200-percent of historical mortality because the area with high mortality decreased. Three watersheds also exhibited increased low mortality, however. Watershed 5 displayed the largest increase in unaffected area and decrease in severely affected stands because the area had recovered from a large stand-replacement fire before 1938. Stands with up to 10-percent dead trees increased, however, indicating that recent insect and disease damage or other disturbance had recently occurred. An unusual pattern of recovery and mortality occurred in watershed 9 where unaffected area increased 23-percent at the same time the area of concentrated mortality increased 100-percent (10-39-percent dead trees) to 200-percent (40-70-percent dead trees).

Logging activity—The area with apparent logging increased in the Deschutes basin by 11-percent and in the Methow basin by 12-percent from historical rates ($P \leq 0.10$) (fig. 19). (Note that changes in area obviously logged, or showing logging activity, were determined as the inverse of changes in the “none-visible” category in fig. 20; an increase in the none-visible category indicated increased logging activity.) Other basins also exhibited increases in logging activity, but high variability among watersheds because of wilderness status or unsuitability for timber harvest, precluded tests of statistical significance. All basins except the Deschutes displayed 2 to 20 times greater area affected by regeneration harvest than in historical times. All watersheds in the Pend Oreille basin indicated up to 20-percent increases in logging, except for watershed 5, which revealed a decline in logging activity over 77-percent of the area since 1935. Selective harvesting increased from 30-percent to over 100-percent in all basins except the Pend Oreille which exhibited a decline in area logged by selection techniques. A 3 to 13-percent increase in selective harvesting occurred in three Pend Oreille watersheds, but the 88-percent decline in selectively harvested area in watershed 5 (which had burned before 1938) had a large negative influence on the mean.

All watersheds in the Yakima basin likewise exhibited increased (up to 50-percent more) logging activity since 1949. Much of the logging in the Yakima basin was split between regeneration and selective harvesting, except in two watersheds (27, 30) with checkerboard ownership, where clearcut area increased from 0 to 2-percent of the area during 1949, to 20-percent of watershed 27 and 50-percent of the area of watershed 30. Logging in the Wenatchee basin occurred primarily in only two sample watersheds, where the visibly logged area increased by 30-percent, with more than 35 to 45-percent of the area of those watersheds modified. Thinning and patch clearcutting increased, but affected less than 2-percent of the sampled area in all basins.

Landscape pattern—Current landscape pattern in five of the six basins was more diverse and fragmented than in the past (fig. 21a-b) as measured by several attributes. Mean patch size decreased 30 to 130-percent ($P \leq 0.10$) and edge density increased 15 to 40-percent ($P \leq 0.10$) in the Deschutes, Methow, and Pend Oreille basins. Patch shape, measured by the fractal index, became more complex ($P \leq 0.10$) in the Deschutes basin. As patch size decreased, patch density increased 17 to 48-percent ($P \leq 0.10$) in the Deschutes and Methow basins. Vegetation composition and landscape diversity increased ($P \leq 0.10$) in the Pend Oreille basin as dominance decreased ($P \leq 0.10$). A decline ($P \leq 0.10$) in patch contagion in the Methow basin also indicated greater vegetation complexity at the 1-ha scale of measurement. These changes in landscape pattern followed the pattern of change expected when timber harvesting is a primary influence. Pattern in the Wenatchee and Yakima basins also followed these trends, although changes over time were not statistically significant.

Change in landscape pattern in the Grande Ronde was entirely different and more closely followed the pattern of change expected when fire suppression activities had effectively excluded fires. Diversity decreased ($P \leq 0.10$) and dominance increased ($P \leq 0.10$), primarily because of the 325-percent increase in the percentage of landscape with midseral stands (fig. 14). Other pattern attributes did not indicate significant change in the Grande Ronde at the basin scale because changes among watersheds were highly variable.

A comparison between wilderness and managed watersheds in the Grande Ronde revealed clear differences in patterns of change and in the role that timber harvest and active fire suppression with a well-developed road system may have played in pattern development. Wilderness watersheds (35, 40, 52, 55) became less diverse and less fragmented than managed watersheds as shown by 24 to 69-percent declines in patch density, whereas, patch density in managed watersheds increased 40 to 100-percent. Patch size increased 30 to 225-percent in wilderness but declined 30 to 50-percent in managed areas. Edge density decreased 30 to 60-percent in wilderness but increased 6 to 35-percent in five of six managed watersheds. Landscape diversity decreased and dominance increased, contagion increased, and edge density decreased in wilderness, whereas managed areas followed opposite trends.

Wilderness watersheds in the other five basins were less conspicuously different than managed watersheds but did show the effects of timber harvest. A close look at the change in landscape pattern attributes in all watersheds in the six basins exhibited considerable variability in the amount of change over time and in the influence of logging activity, and it indicated some thresholds of landscape change. A line fitted to the scatterplot of the change over time in landscape attributes against the current visible percentage of area logged should be level if logging has no influence. Scatter around the line shows the residual variation, or variation in change that is explained by other factors such as fire suppression and natural succession. Patch density increased with logging up to a threshold of 30-percent affected area. Beyond that, patch density did not increase (fig. 22). Residual scatter was high even when very little logging occurred, especially above the fitted line, which indicated other disturbances made important contributions to the higher patch densities now observed. Edge density and fractal patch shape complexity had similar relations with the area logged (fig. 22), but residual variation was more evenly distributed, indicating that negative and positive changes were equally frequent and often associated with other factors. Logging had a negative influence on patch size (fig. 22), although decreases in patch size were evident in the absence of logging, probably as a result of insect and disease disturbance. This effect of fragmenting the landscape was also shown by the relation between logging and landscape contagion (fig. 23). Diversity of vegetation composition and structure did

not appear to be influenced by logging (fig. 24); diversity was slightly higher now than in the past, regardless of logging activity. Dominance also changed little during the study period, and logging had little effect on it (fig. 24).

Insect and Disease Hazard

Insect and disease hazards changed little at the river basin scale (fig. 24a-b) because variation at the watershed scale was considerable. Basin-scale changes were usually less than 10-percent difference from the historical conditions, even when shown to be statistically significant ($P \leq 0.1$). Moreover, changes in hazard among basins were often inconsistent in the direction of change, except perhaps for western dwarf mistletoe hazard, which increased substantially in the Grande Ronde (29-percent) and Pend Oreille (11-percent) basins. Large changes in insect and disease hazards were common in individual watersheds, however, which indicated watersheds were the appropriate scale for hazard analyses of many insects and diseases.

Analysis of the distribution of hazard scores for all watersheds revealed a preponderance of change within ± 10 -percent above or below historical ratings, with some watersheds exhibiting larger changes in both positive and negative directions. Increases and decreases in hazard for all species evaluated were fairly well distributed across all basins. Within sampled watersheds, hazard from defoliators declined in slightly more watersheds than it increased (fig. 25). The large increases in defoliator hazard occurred in watersheds of the Grande Ronde, Methow, Deschutes, and Pend Oreille basins. In general, defoliator hazards decreased or stayed the same in sample watersheds of the Wenatchee and Yakima basins.

Douglas-fir beetle hazards increased more often than they decreased, with seven watersheds in the Grande Ronde, Methow, and Yakima basins showing 30 to 60-percent increases (fig. 26). Western pine beetle Type 1 hazard to overmature ponderosa pine decreased in about 20-percent of sample watersheds, and increased in 10-percent of the watersheds. In some Deschutes watersheds, increases of 50 to 60-percent were evident (fig. 26). Western pine beetle Type 2 hazard to immature ponderosa pine followed a trend similar to Type 1 hazard (fig. 26), with most of the large increases occurring in Deschutes and Grande Ronde watersheds.

Mountain pine beetle Type 1 hazard to overstocked lodgepole pine increased by 1 to 10-percent or remained unchanged in about 50-percent of the watersheds (fig. 26). Some individual watersheds displayed a 5 to 10-percent increase in Type 2 mountain pine beetle hazard (fig. 26), and a few increases in hazard as great as 30 to 70-percent have occurred in some Deschutes, Grande Ronde, and Methow watersheds. Change in fir engraver hazards were evenly split, with 45-percent of the watersheds exhibiting as much as a 10-percent increase in hazard (fig. 26). The greatest decreases (20 to 38-percent) in fir engraver hazard occurred in sample watersheds of the Grande Ronde basin.

Mistletoe hazards increased in at least half of all watersheds. Most watersheds that experienced an increase changed by 5 to 10-percent (fig. 25). Douglas-fir dwarf mistletoe hazard increased the greatest in Grande Ronde and Pend Oreille watersheds. Douglas-fir dwarf mistletoe hazard increased in nearly every Grande Ronde watershed, with some increases as great as 50 to 90-percent. Mistletoe hazard in Douglas-fir decreased in all but one sample watershed in the Yakima basin. The largest increases in hazard associated with western dwarf mistletoe occurred in Deschutes and Grande Ronde watersheds. Western larch dwarf mistletoe hazards decreased or remained the same in most sample watersheds.

Root disease hazards increased in 50-percent of the sampled watersheds (fig. 25). The greatest increase in root disease hazard occurred in the Pend Oreille basin, where hazard increased in all watersheds. Large increases were also noted in some Grande Ronde and Deschutes watersheds.

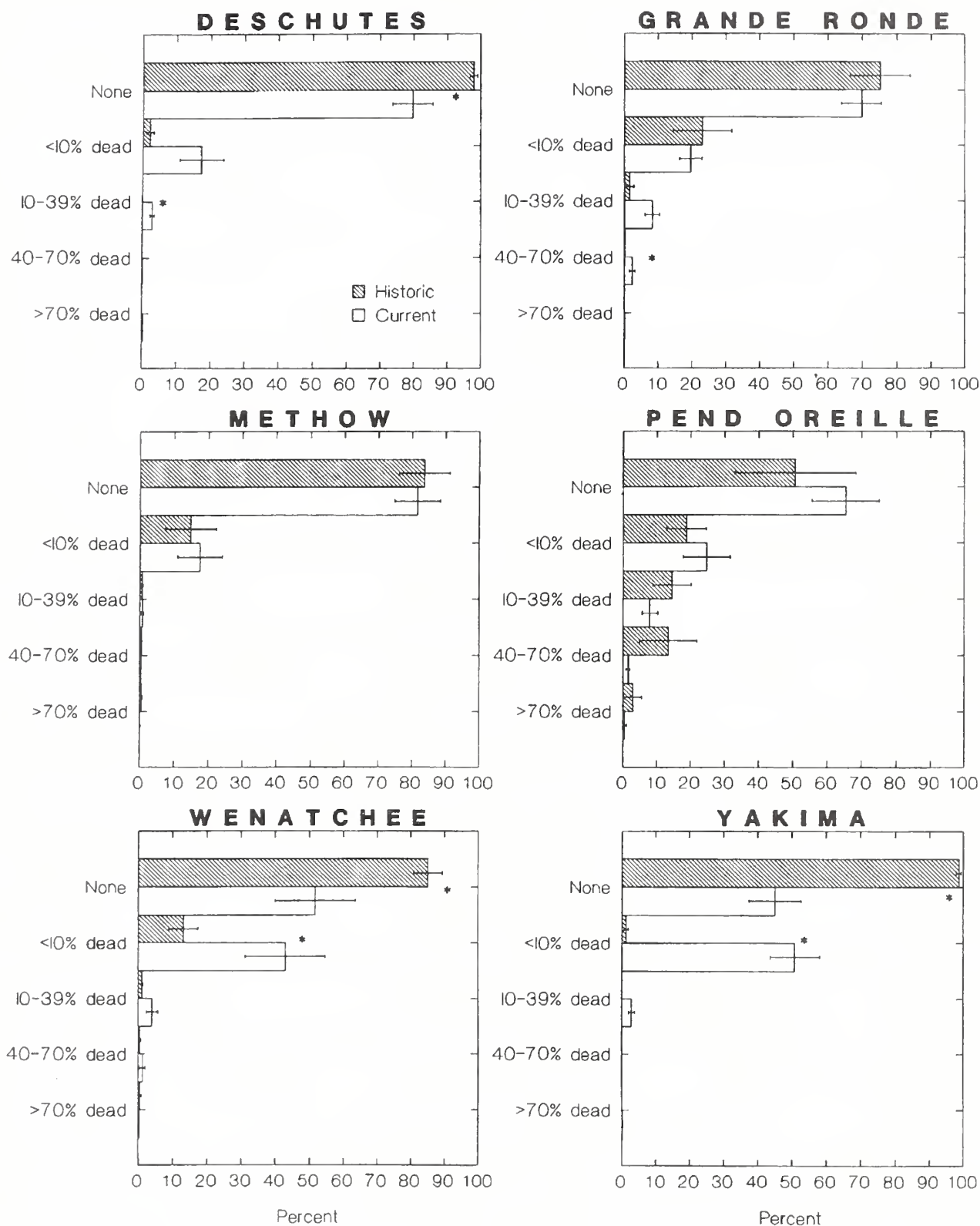


Figure 20—Historical and current percentages of dead trees in forested stands expressed as a percentage of total area on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

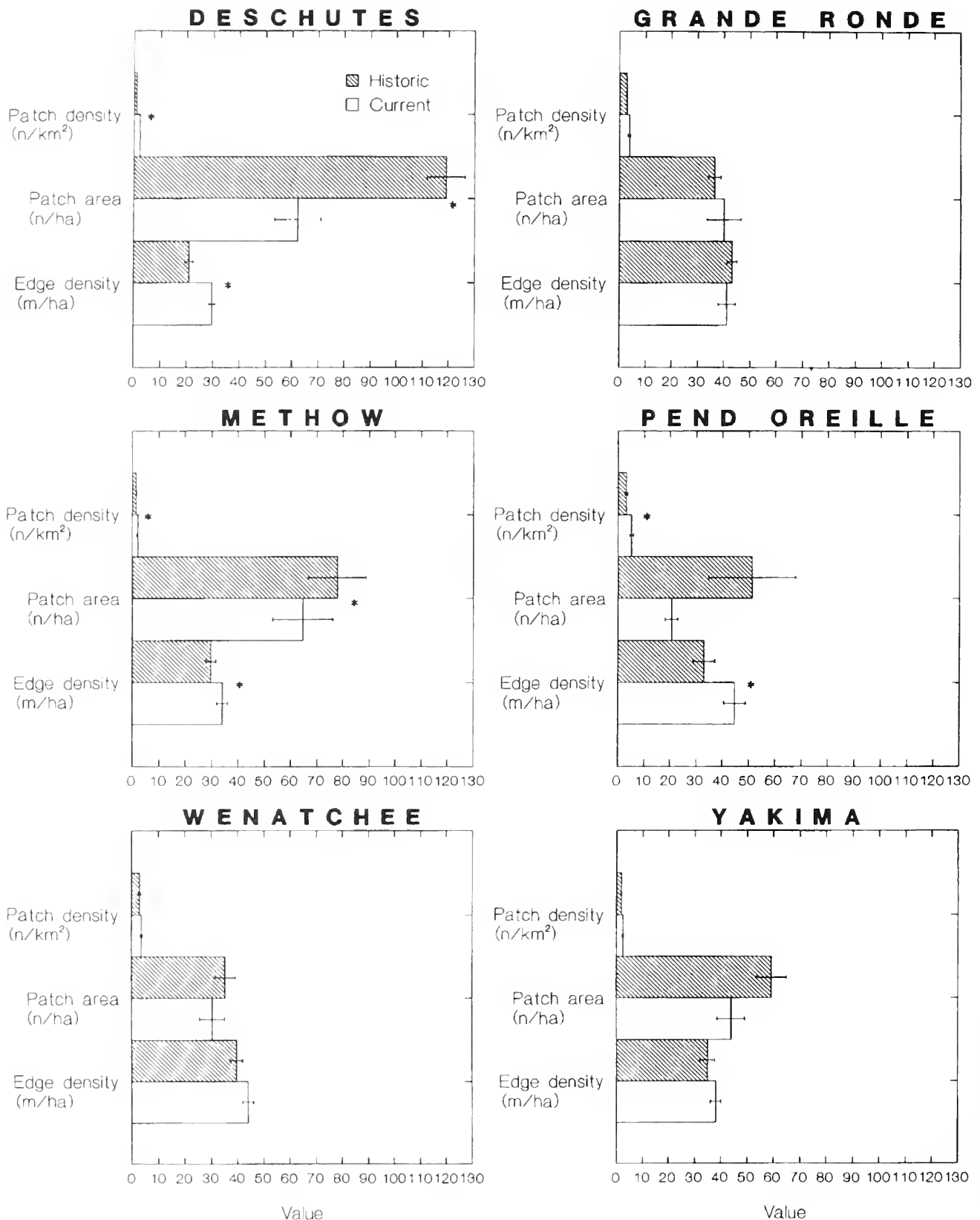


Figure 21a—Historical and current vegetation patch density (n/km²), mean patch area (ha), and edge density (m/ha) on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

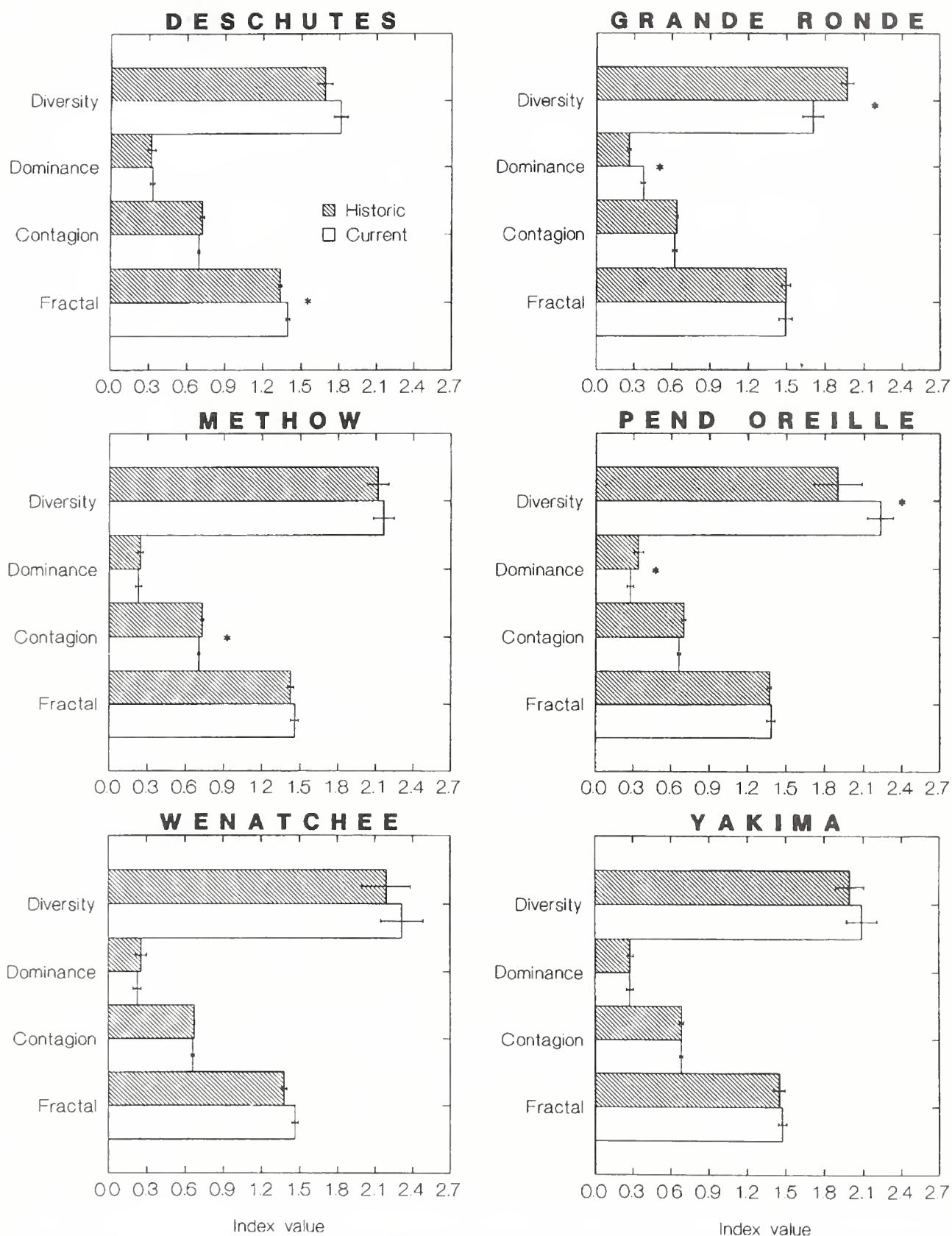


Figure 21b—Historical and current vegetation pattern indices on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

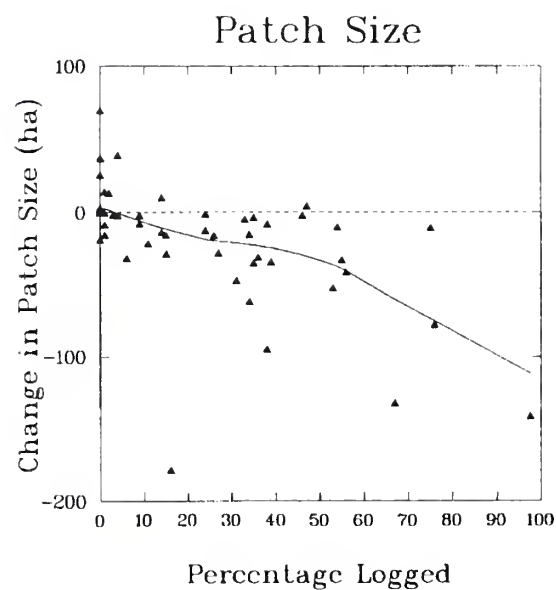
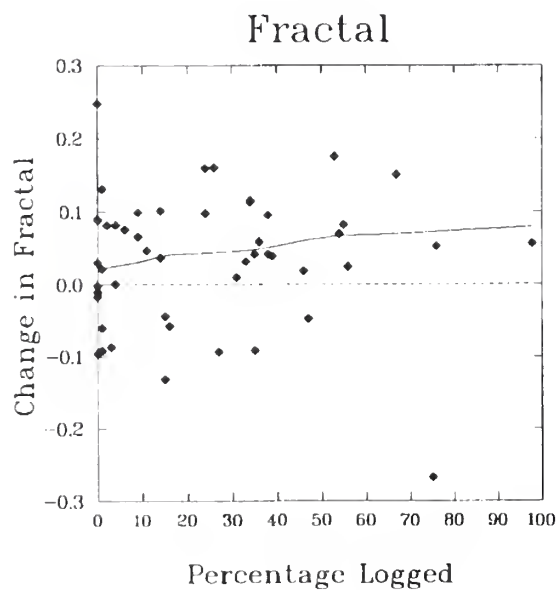
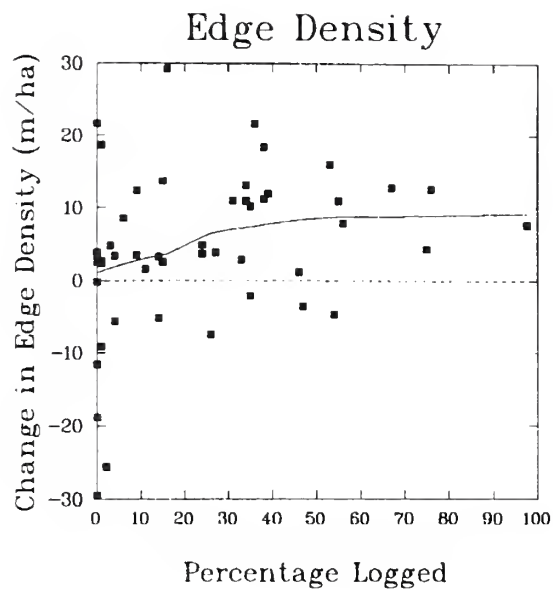
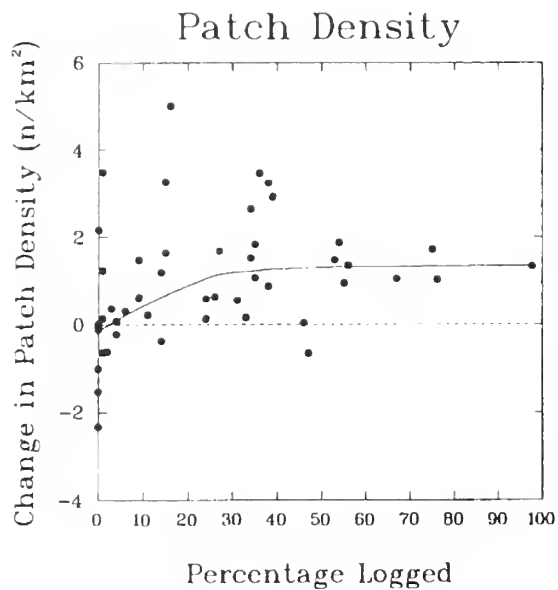


Figure 22—Percentage change from historical to current times in patch density, edge density, fractal index of patch shape complexity, and patch size vs. the percentage area logged in 49 watersheds in six river basins, eastern Oregon and Washington. Curve was fitted by weighted average (Lowess) smoothing.

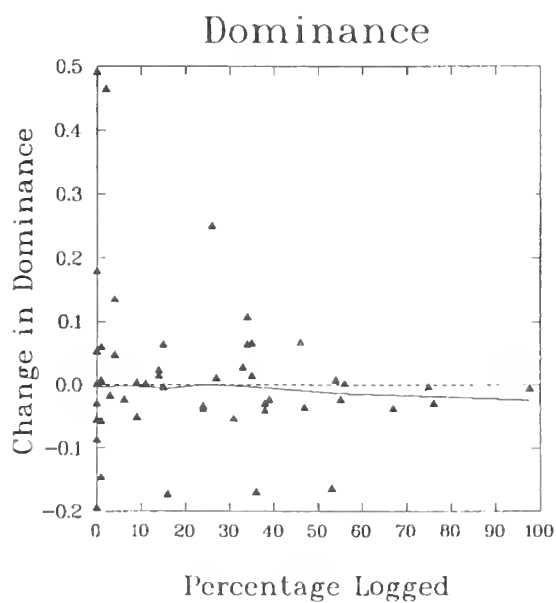
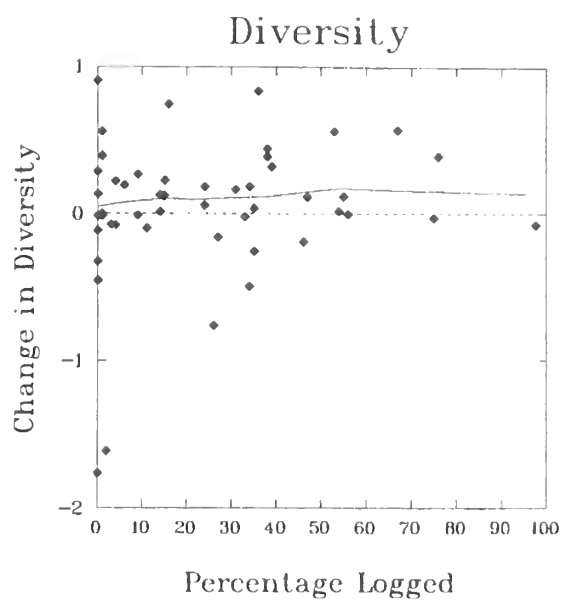
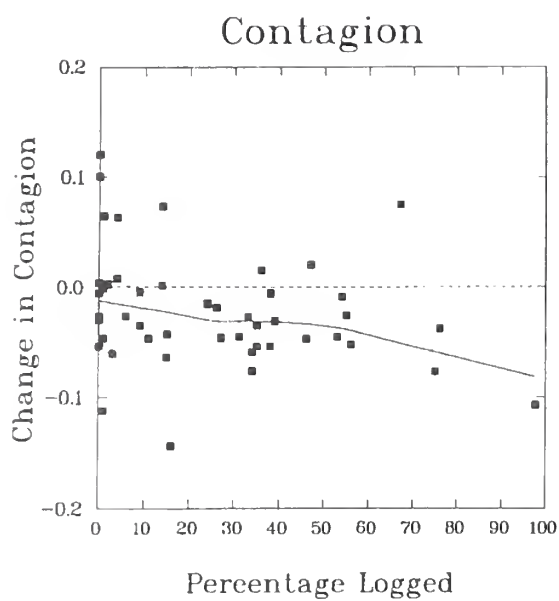


Figure 23—Percentage change from historical to current times in contagion, diversity, and dominance vs. the percentage area logged in 49 watersheds in six river basins, eastern Oregon and Washington. Curve was fitted by weighted average (Lowess) smoothing.

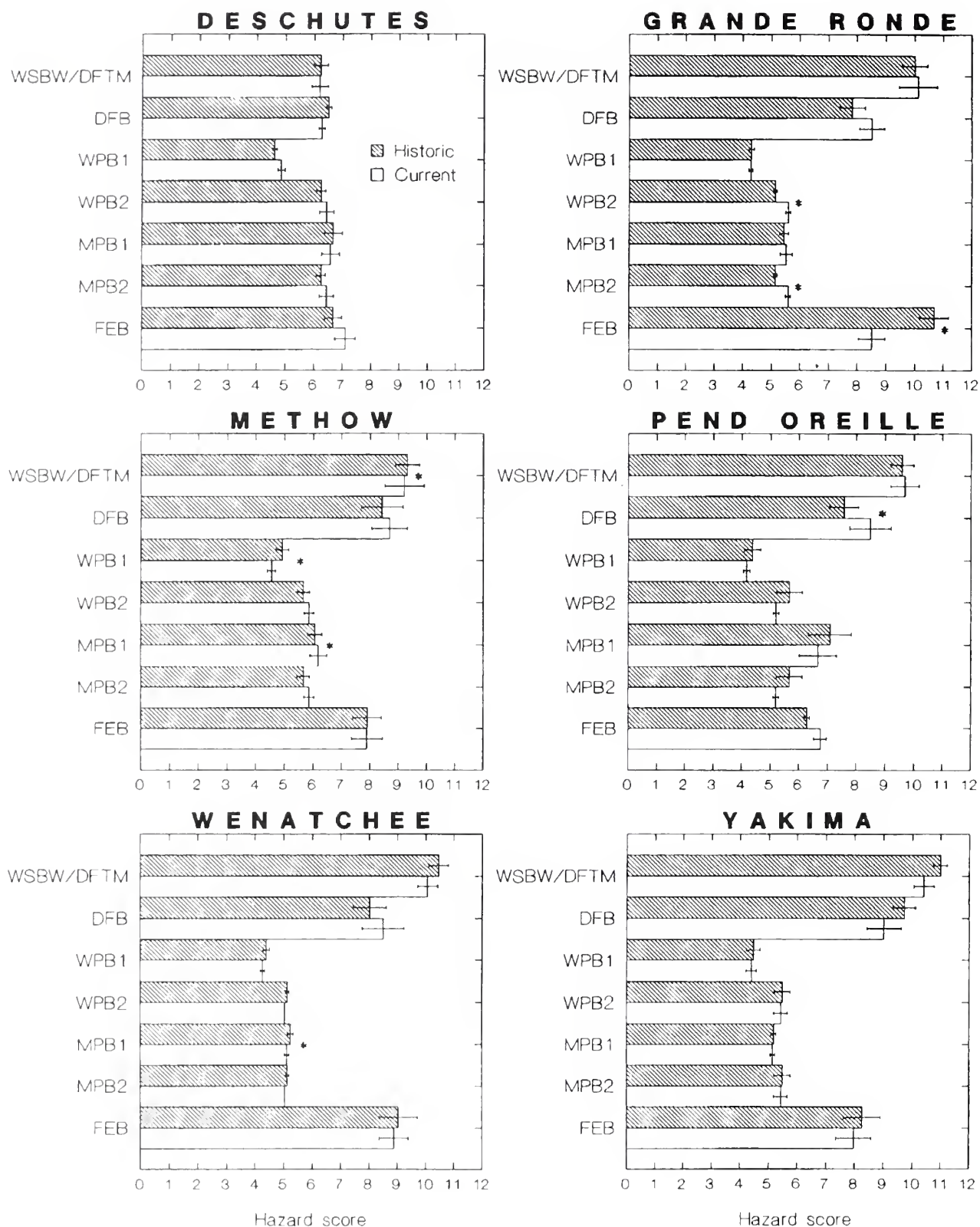


Figure 24a—Historical and current indices of insect and disease hazard on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions. Species codes: WSBW/DFTM = western spruce budworm or Douglas-fir tussock moth; DFB = Douglas-fir beetle; WPB1 = western pine beetle type 1; WPB2 = western pine beetle type 2; MPB1 = mountain pine beetle type 1; MPB2 = mountain pine beetle type 2; FEB = fir engraver beetle.

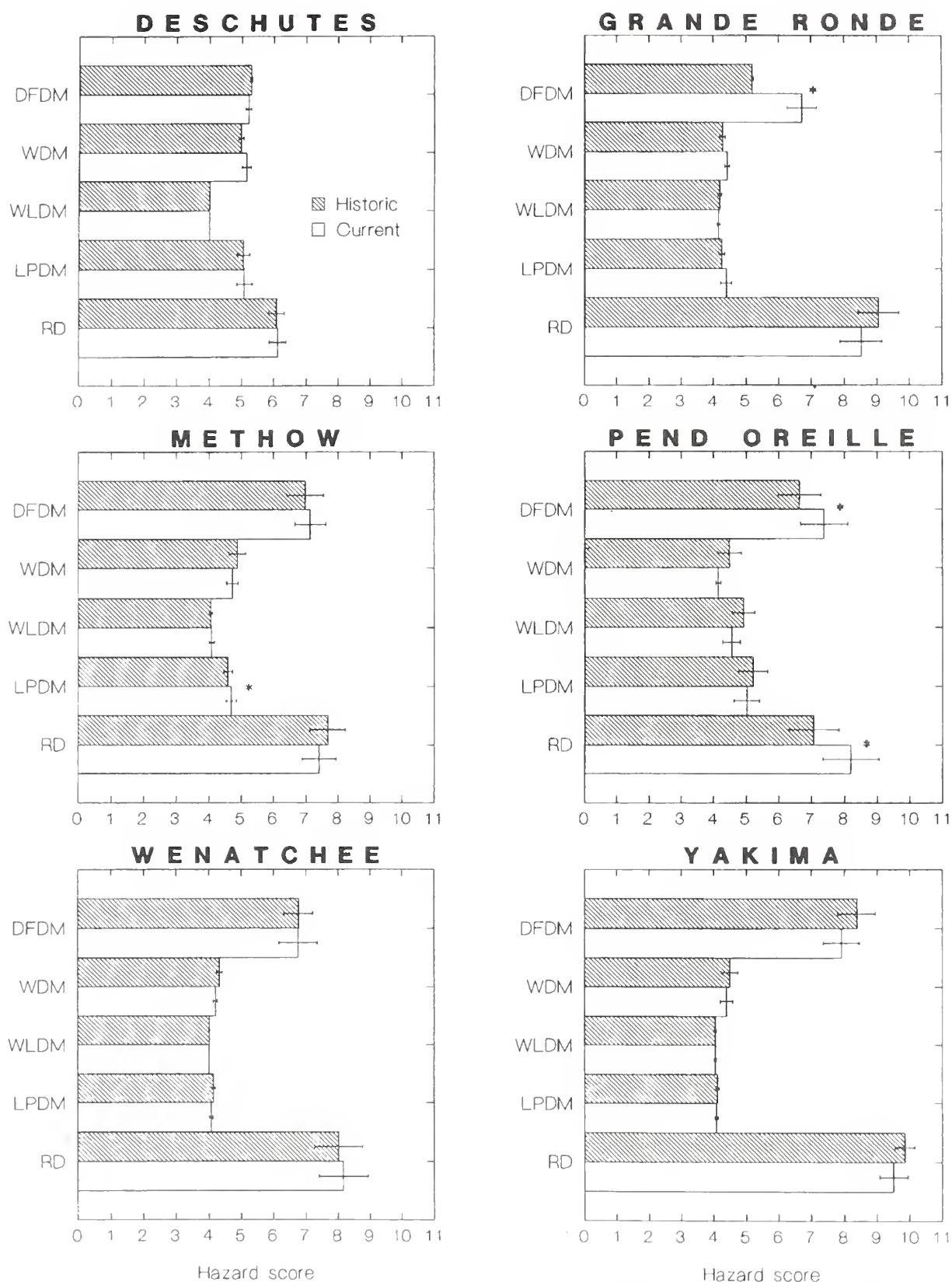


Figure 24b—Historical and current indices of insect and disease hazard on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions. Species codes: DFDM = Douglas-fir dwarf mistletoe; WDM = western dwarf mistletoe; WLDM = western larch dwarf mistletoe; LPDM = lodgepole pine dwarf mistletoe; RD = root disease.

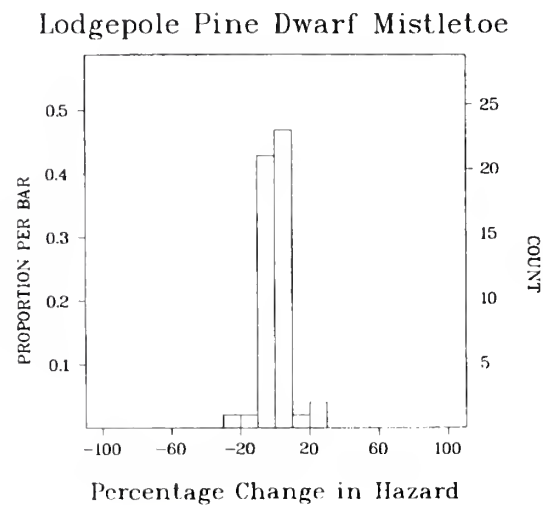
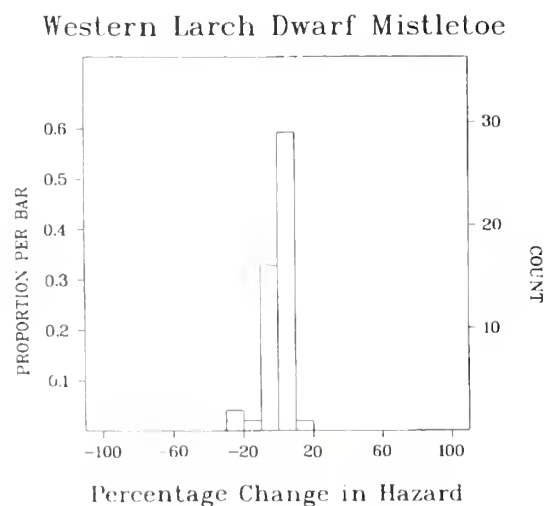
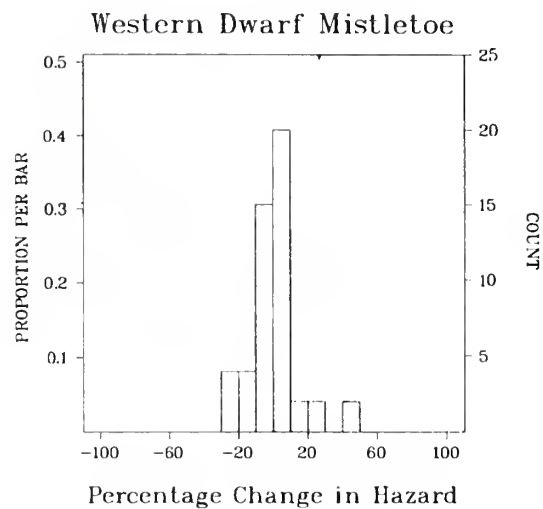
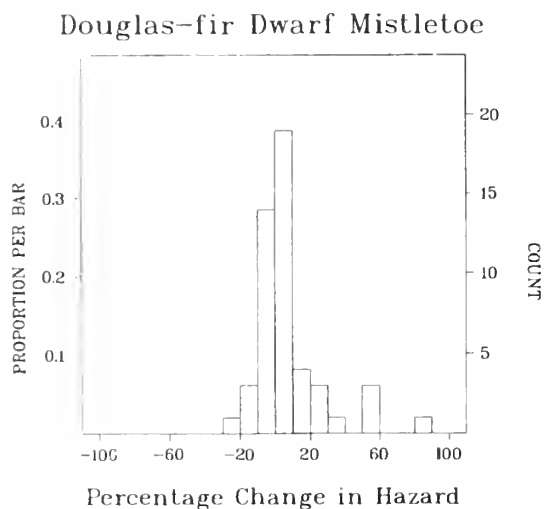
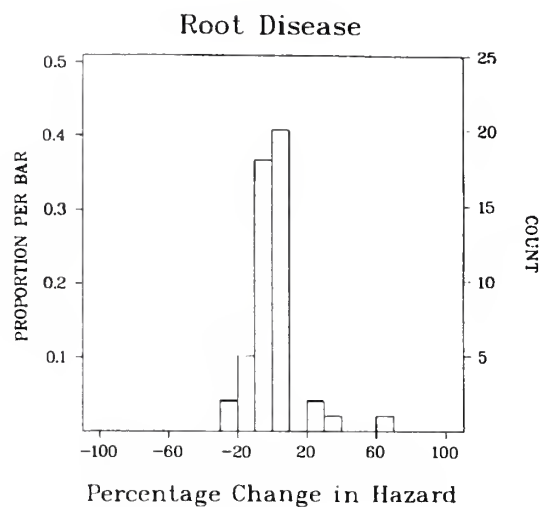
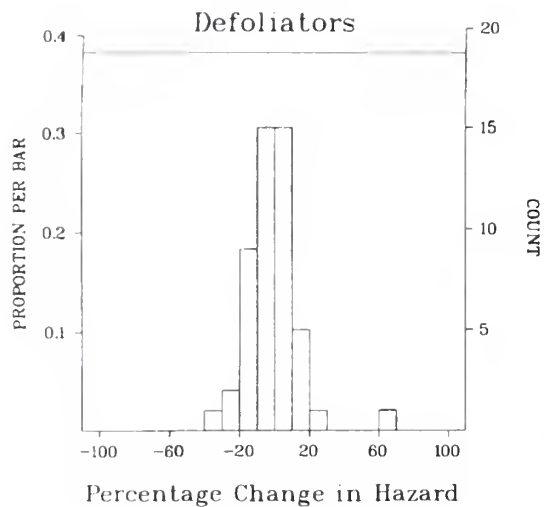


Figure 25— Distributions of percentage change from historical to current times for insect defoliator, root disease, and mistletoe hazard in 49 watersheds in 6 river basins, eastern Oregon and Washington.

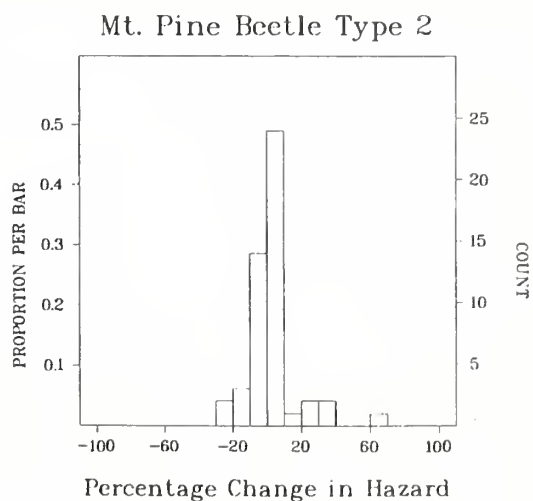
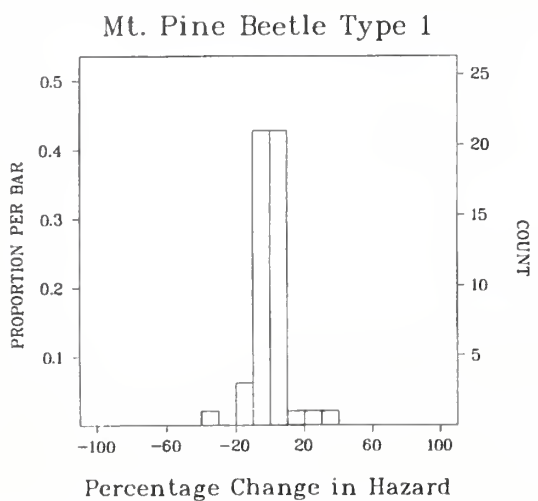
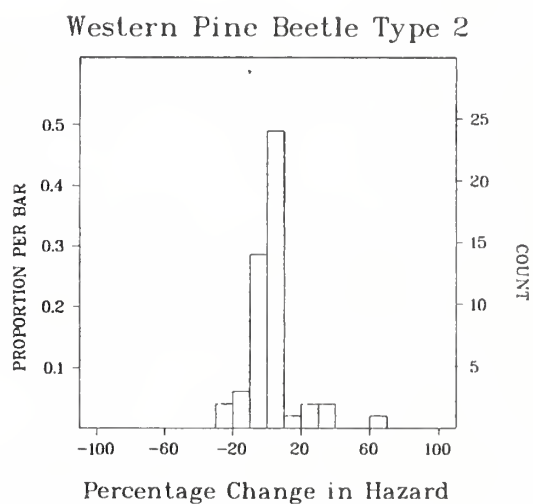
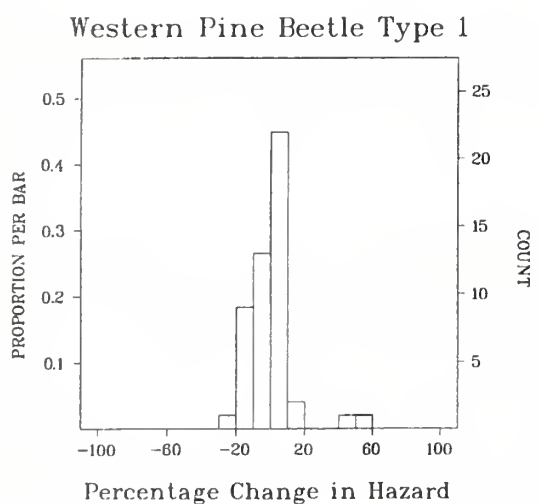
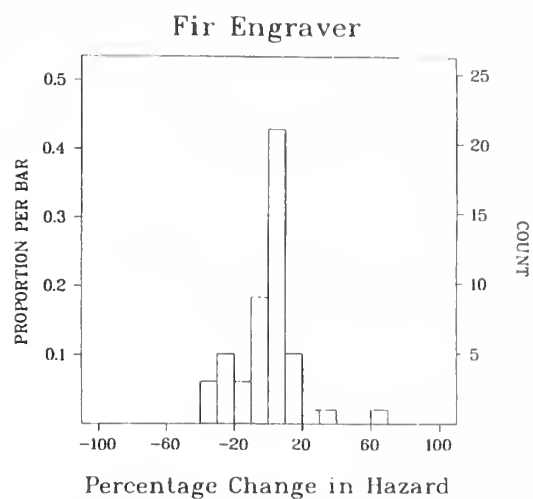
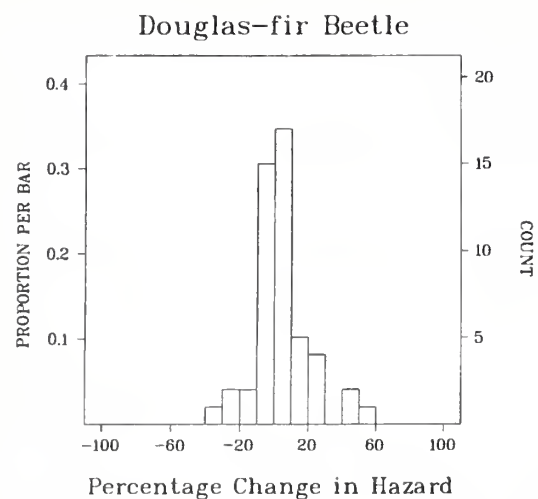


Figure 26—Distributions of percentage change from historical to current times for bark beetle hazard in 49 watersheds in 6 river basins, eastern Oregon and Washington.

Fire

Fuel loading—Fuel-loading averages for the six river basins ranged from 75.3 mg/ha (megagram or metric ton/hectare) on the Methow River basin (current), to 102.7 mg/ha on the Yakima River basin (historical) (fig. 27, appendix C). Fuel-loading differences between the historical and current periods at the river basin scale were very small, ranging from an increase of 7.9 mg/ha on the Deschutes River basin to a decrease of 11.7 mg/ha on the Yakima River basin. Basin differences were not statistically significant ($P > 0.10$).

Although statistical tests indicated no significant differences between historical and current fuel loadings at the basin scale, many of the sample watersheds within a river basin displayed large changes. For example, the Grande Ronde River basin exhibited a decrease of 1.2 mg/ha in fuel loading; but watershed 35 decreased 46.8 mg/ha (figs. 28, 29; appendix C). This watershed was in the Eagle Cap Wilderness area, where no harvesting activities occurred in the past.

Reviewing the vegetation change as recorded by the aerial photograph interpretations, we noted that a major vegetation shift had occurred. Subalpine fir and Engelmann spruce forests decreased from 69 to 30-percent of the area, and whitebark pine and subalpine larch forests increased from 0 to 38-percent. Further investigation indicated that the area had been burned during several wildfire episodes in the past 20 years, which accounted for the shift in vegetation type and decreased fuel loading.

Grande Ronde watershed 55 exhibited the opposite trend: displaying an increase of 35.9 mg/ha in fuel loading from historical to current conditions (fig. 28, 30; appendix C). Watershed 55 is 60 miles north of watershed 35 and is within the Wenaha-Tucanón Wilderness, where no harvesting or large wildfires had occurred since 1970. A major shift in vegetation type was noted via photo interpretation. The watershed changed from an open ponderosa pine and young Douglas-fir stand to an older stand dominated by Douglas-fir and true fir that had few open areas, which accounted for an increase in fuel loading over time.

The Yakima River basin displayed no significant difference between historical and current fuel loading; however, a decrease of 54.0 megagrams/hectare in fuel loading was noted in sample watershed 30 (fig. 28; appendix C). A combination of wildfire and harvest activity shifted some older vegetation types to younger types with lower fuel loading. Uneven-aged old-growth true fir, western hemlock, and western redcedar forest decreased from 41-percent of the area to 5-percent. Young, even-aged true fir, western hemlock, and western redcedar increased from 7 to 28-percent; the young, even-aged Douglas-fir and true fir stands increased from 1 to 21-percent.

Fire behavior—No statistically significant fire behavior differences between current and historical conditions were detected in any of the six river basins at the basin-scale. Mean ROS in current conditions ranged from 1.77 to 3.21 m/min in the Wenatchee and Grande Ronde River basins, respectively. Historical conditions similarly ranged from 1.50 to 4.00 in those basins (fig. 32; appendix C). In current landscapes, only the mean ROS in the Grande Ronde River basin exceeded the crucial rate of 2.5 m/min where initial control efforts would be difficult. Even though predicted ROS in current conditions exhibited that fire control efforts would be difficult in the Grande Ronde, this river basin displayed the largest ROS decrease, 0.79 m/min, from the past to the present. The greatest increases in ROS between historical and current rates were observed in the Yakima and Wenatchee River basins, although these increases were not statistically significant ($P \leq 0.10$).

Mean FL, a parameter that conveys a sense of fire intensity (Rothermel 1991) in current landscapes was greatest in the Grande Ronde and least in the Wenatchee River basins (fig. 33, appendix C). In historical landscapes, mean potential FL was highest in the Pend Oreille basins and lowest in the Methow River basin. None of the river-basin means examined in either current or historical periods closely approached the crucial level of 2.3 m flame lengths where initial control efforts would be difficult. Few of the river

basins exhibited much change in mean FL from historical to current conditions. The largest increase and decrease were in the Grande Ronde and Pend Oreille, respectively, although these differences were also not statistically significant ($P \leq 0.10$).

Mean RTS, a subjective assessment of the time it takes to construct firelines under different fuel conditions, in current and historical landscapes was lowest (most difficult to construct fireline) in the Pend Oreille basin and highest (least difficult) in the Methow River basin (fig. 34; appendix C). Most river basins exhibited little change in mean RTS between historical and current conditions, especially the Deschutes, Grande Ronde, and Methow River basins. The Wenatchee basin displayed the largest change in mean RTS (not statistically significant), with rate of potential fireline built increasing from 0.73 to 0.89 m/min.

Change from historical to current conditions was not consistent among the sample watersheds because both increases and decreases of ROS and FL were evident in all river basins (figs. 35, 36; and table 3). A finding of no significant change between historical and current ROS and FLs at the river basin-scale resulted from this high variability. Change in ROS from historical to current conditions varied most in the Deschutes, Grande Ronde, and Yakima River basins (table 3). FL varied most in the Deschutes, Grande Ronde, and Pend Oreille River basins. Increases in ROS and FL were detected in 50-percent or more of the sample watersheds in all but the Grande Ronde and Wenatchee basins (table 3).

Current conditions in all river basins had 20-percent of the sample watersheds with $ROS > 2.5$ m/min, above where initial control effort would be difficult (table 4). In the Grande Ronde river basin 60-percent, and in the Deschutes River basin 50-percent, of the sample watersheds were above this critical threshold. Four of the six river basins had more sample watersheds above the critical threshold in the current condition than in the historical condition. No sample watersheds had FL that exceeded 2.3 m in current or historical conditions (table 4).

In general, ROS and FL were positively correlated with proportion of area logged (hereafter, area logged) in the sample watersheds. Area logged was correlated with ROS ($r \geq 0.53$) in five of six river basins (table 5). ROS in the Pend Oreille and Wenatchee River basins was strongly associated with area logged ($r \geq 0.95$). Correlations of area logged by harvesting technique indicated that harvesting by clearcut and by shelterwood were most strongly associated with increasing ROS.

Area logged was positively correlated with FL ($r \geq 0.63$) in four of six river basins (table 5). Deschutes, Methow, and Wenatchee River basins displayed the strongest relations. Harvest techniques having the strongest association with increasing FL were clearcut, shelterwood, and selective harvest.

Sample watersheds in the Grande Ronde and Yakima River basins shown in figures 37, 38, and 39 illustrate that ROS and FL patterns were diverse at a watershed scale and could change substantially from historical to the present. The two Grande Ronde watersheds were unlogged, primarily high-elevation ecosystems in wilderness areas with two different disturbance patterns. Forests in the Eagle Cap Wilderness example (appendix E) had several large wildfires in the past, but the Wenaha-Tucanón Wilderness example (appendix E) had none. Even though different landscape patterns and processes have ensued and fuel complexes differed, both sample watersheds displayed 100-percent declines in ROS for surface and understory fires between historical and current periods. In the Wenaha-Tucanón Wilderness, however, where fires have been absent, FL increased about 35-percent. In the example from the Yakima River basin (appendix E), where harvesting activities have been conspicuously high, ROS increased more than 300-percent and FL increased more than 40-percent from historical to current conditions.

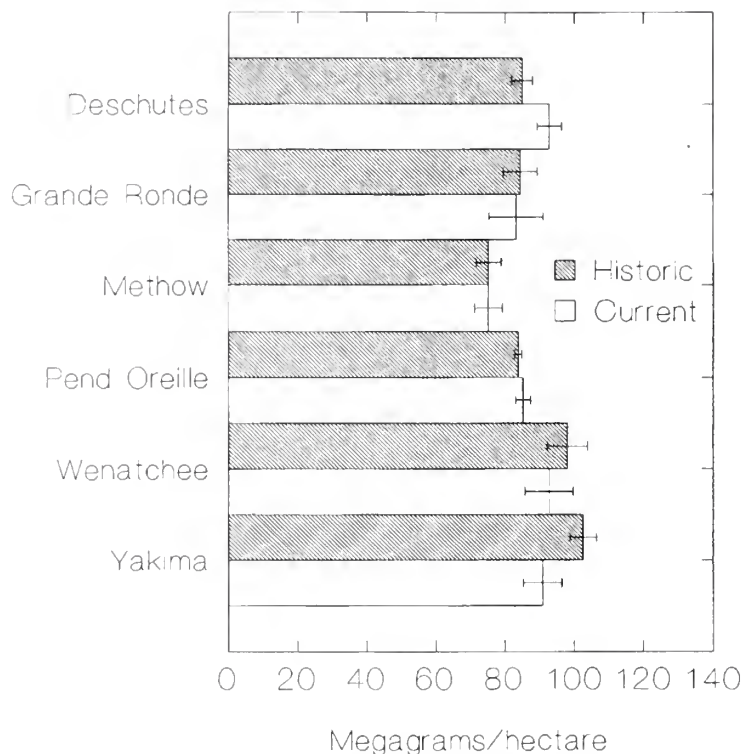


Figure 27—Historical and current fuel loading averages on lands within National Forest boundaries in river basins of eastern Oregon and Washington. Error bars are the standard error of the stratified mean estimate.

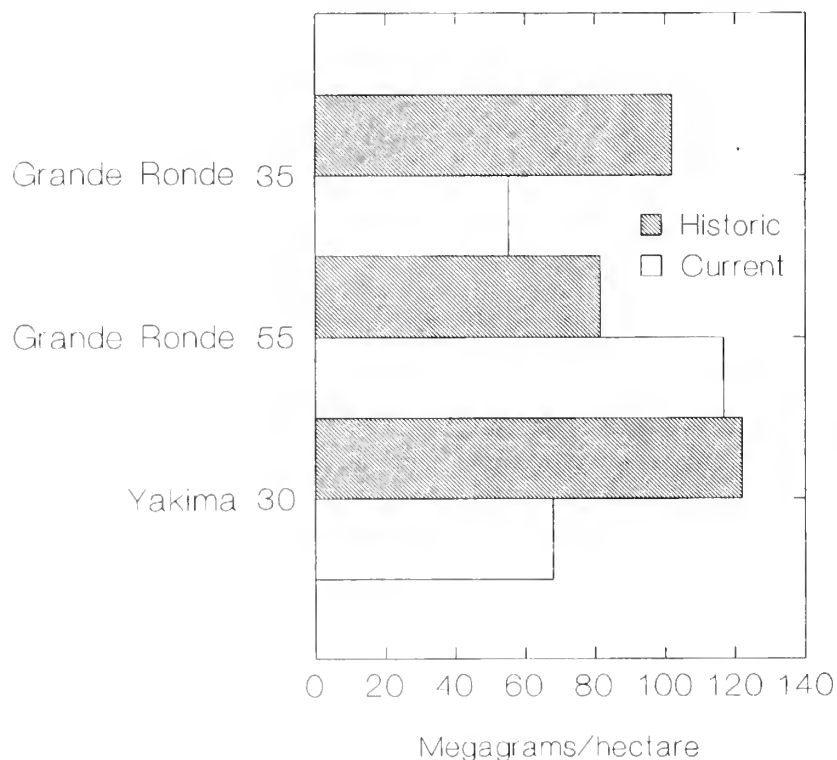


Figure 28—Historical and current fuel loading averages for selected sample watersheds in the Grande Ronde river basin, eastern Oregon.

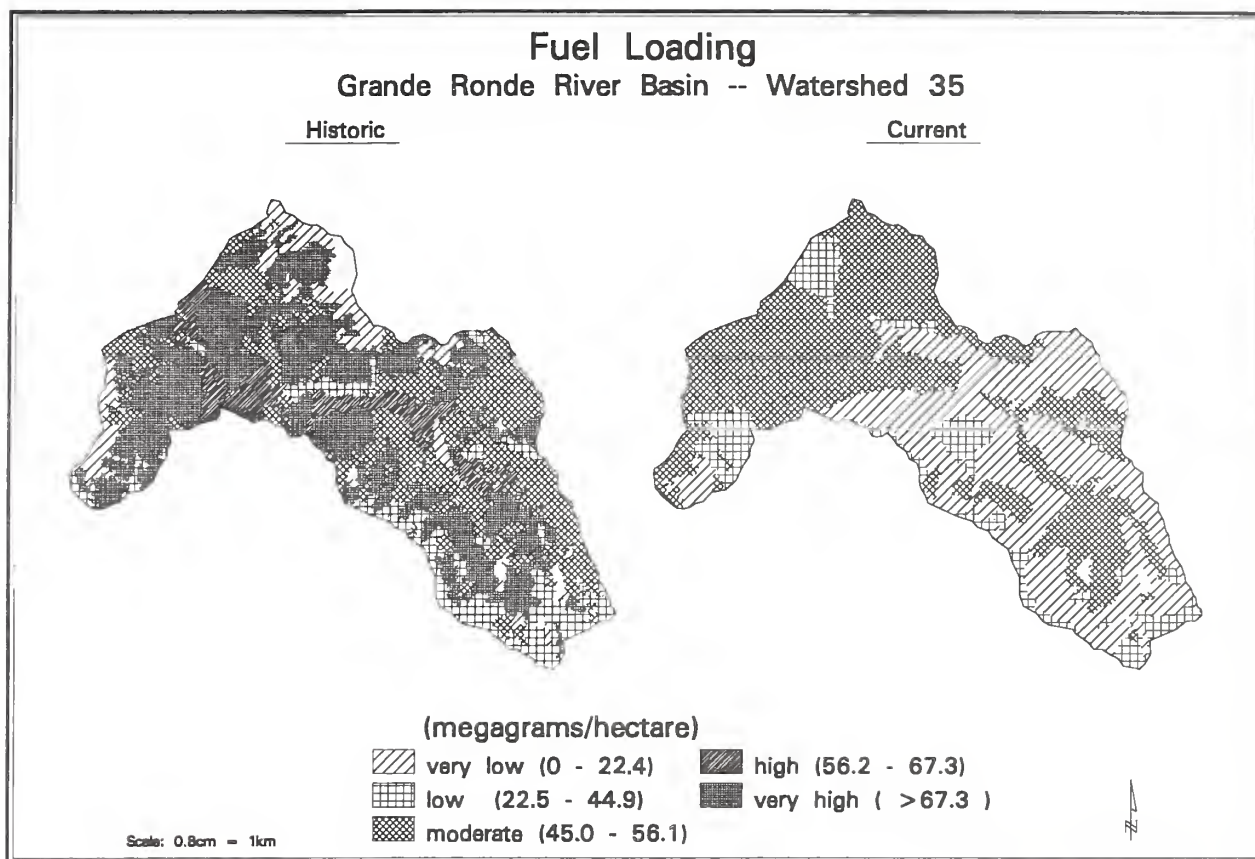


Figure 29—Historical and current fuel loading maps for sample watershed 35 in the Grande Ronde River basin, eastern Oregon.

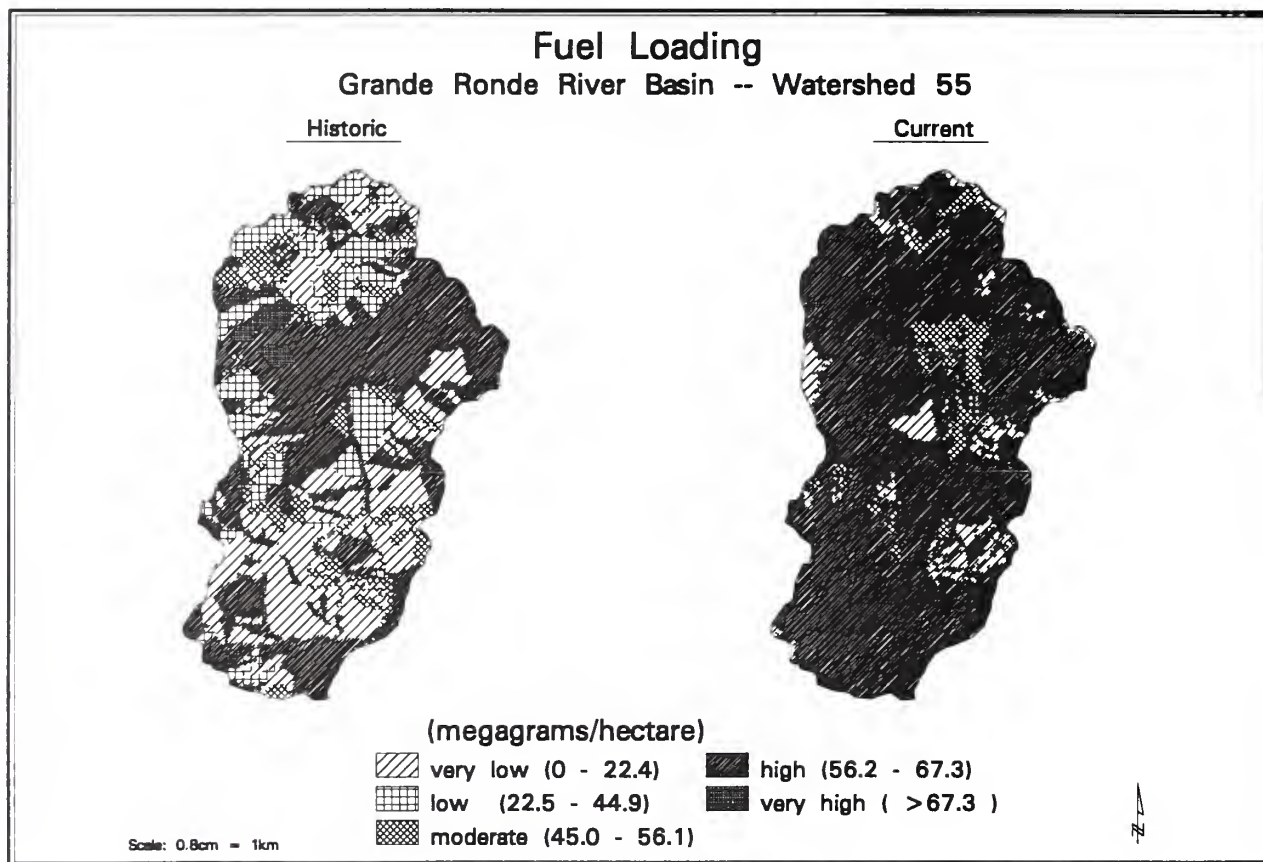


Figure 30—Historical and current fuel loading maps for sample watershed 55 in the Grande Ronde River basin, eastern Oregon.

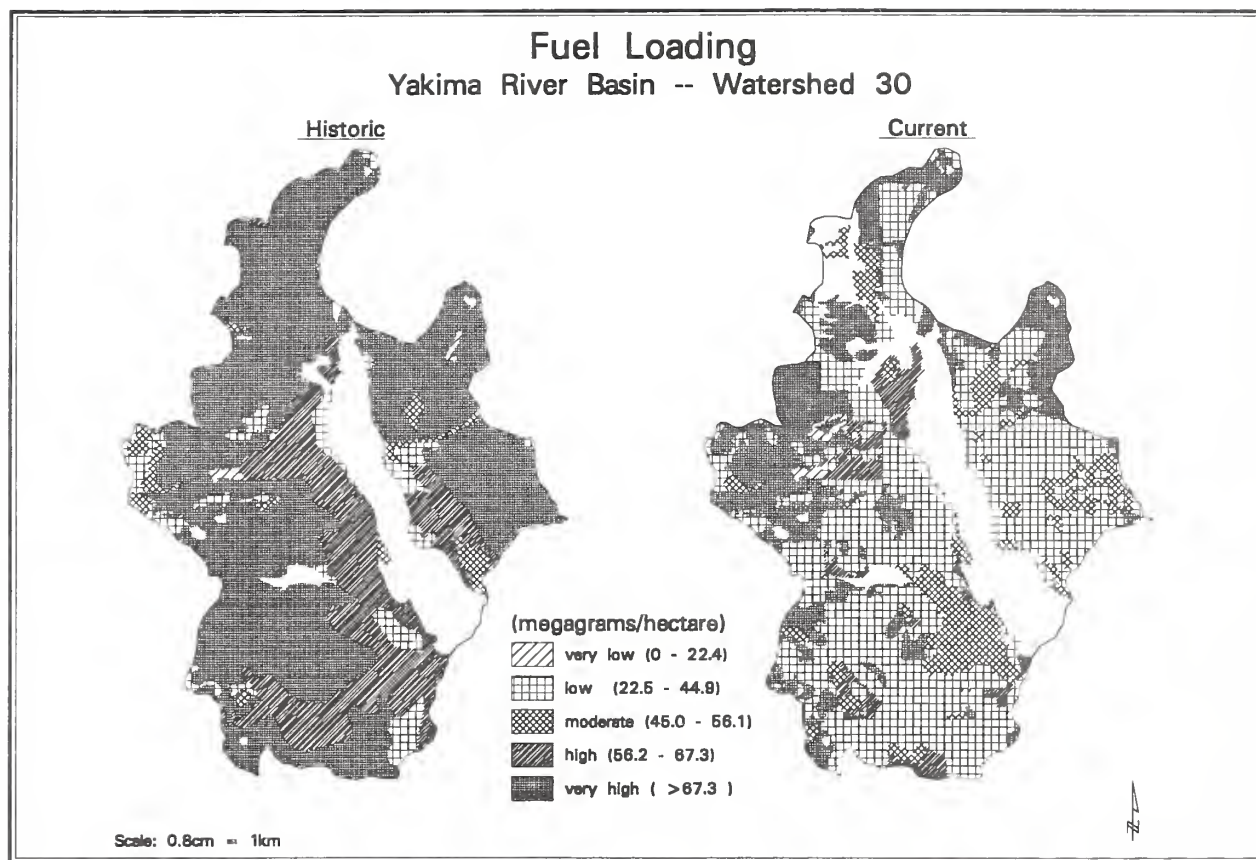


Figure 31—Historical and current fuel loading maps for sample watershed 30 in the Yakima River basin, eastern Washington.

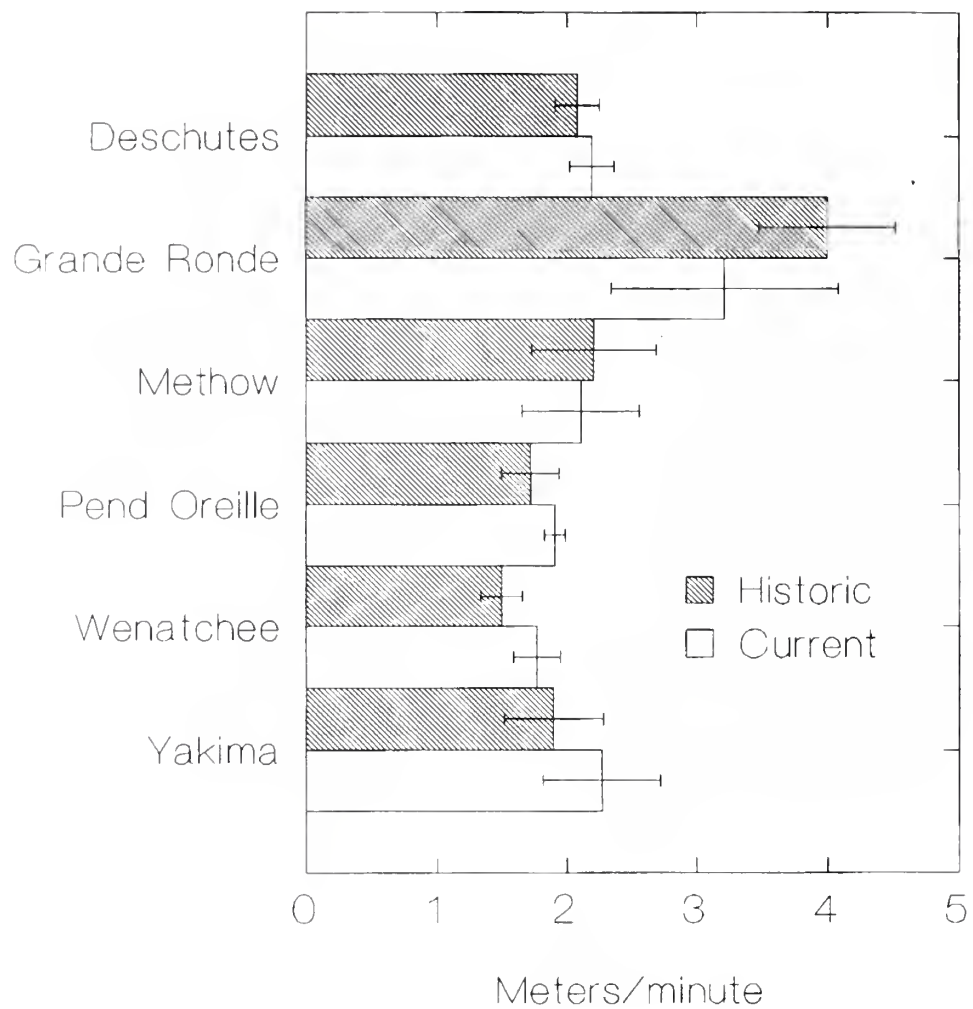


Figure 32—Historical and current mean potential rates of fire spread on lands within National Forest boundaries in river basins of eastern Oregon and Washington. Error bars are the standard error of the stratified mean estimate.

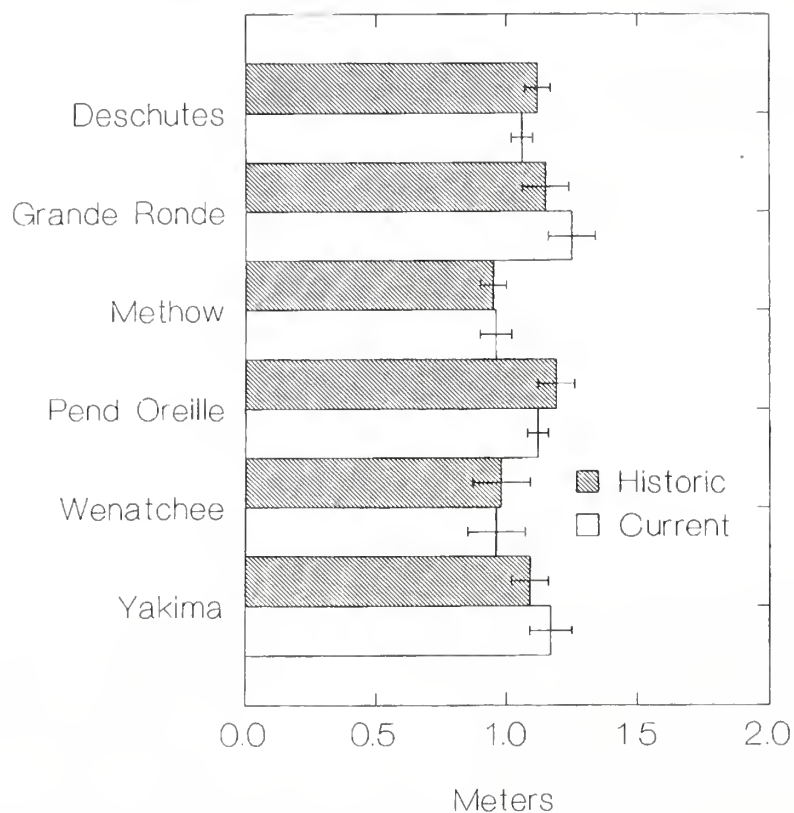


Figure 33—Historical and current mean potential flame lengths on lands within National Forest boundaries in river basins of eastern Oregon and Washington. Error bars are the standard error of the stratified mean estimate.

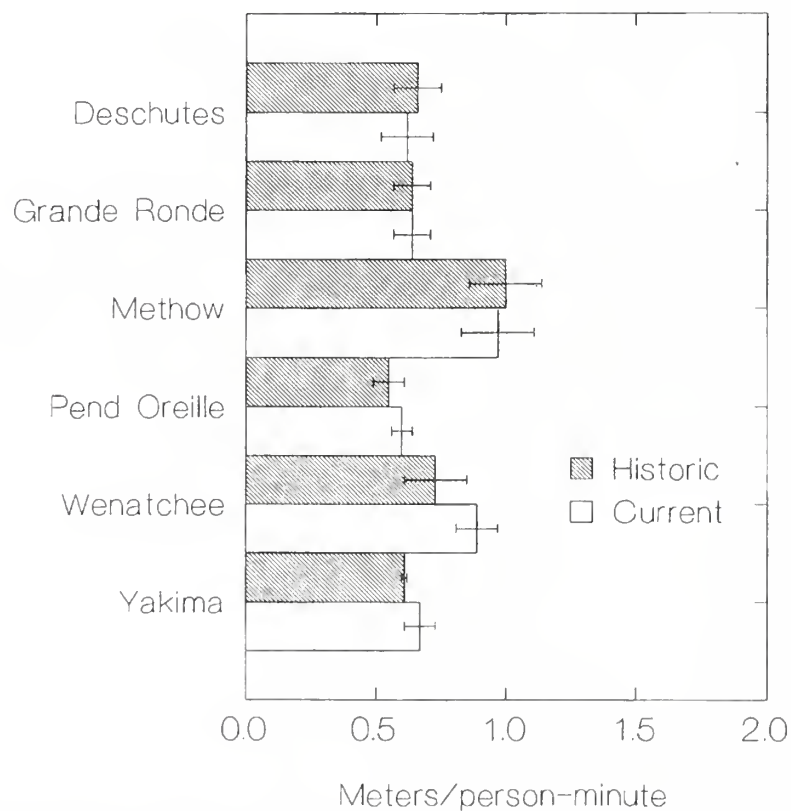


Figure 34—Historical and current mean potential resistance to fire suppression on lands within National Forest boundaries in river basins of eastern Oregon and Washington. Error bars are the standard error of the stratified mean estimate.

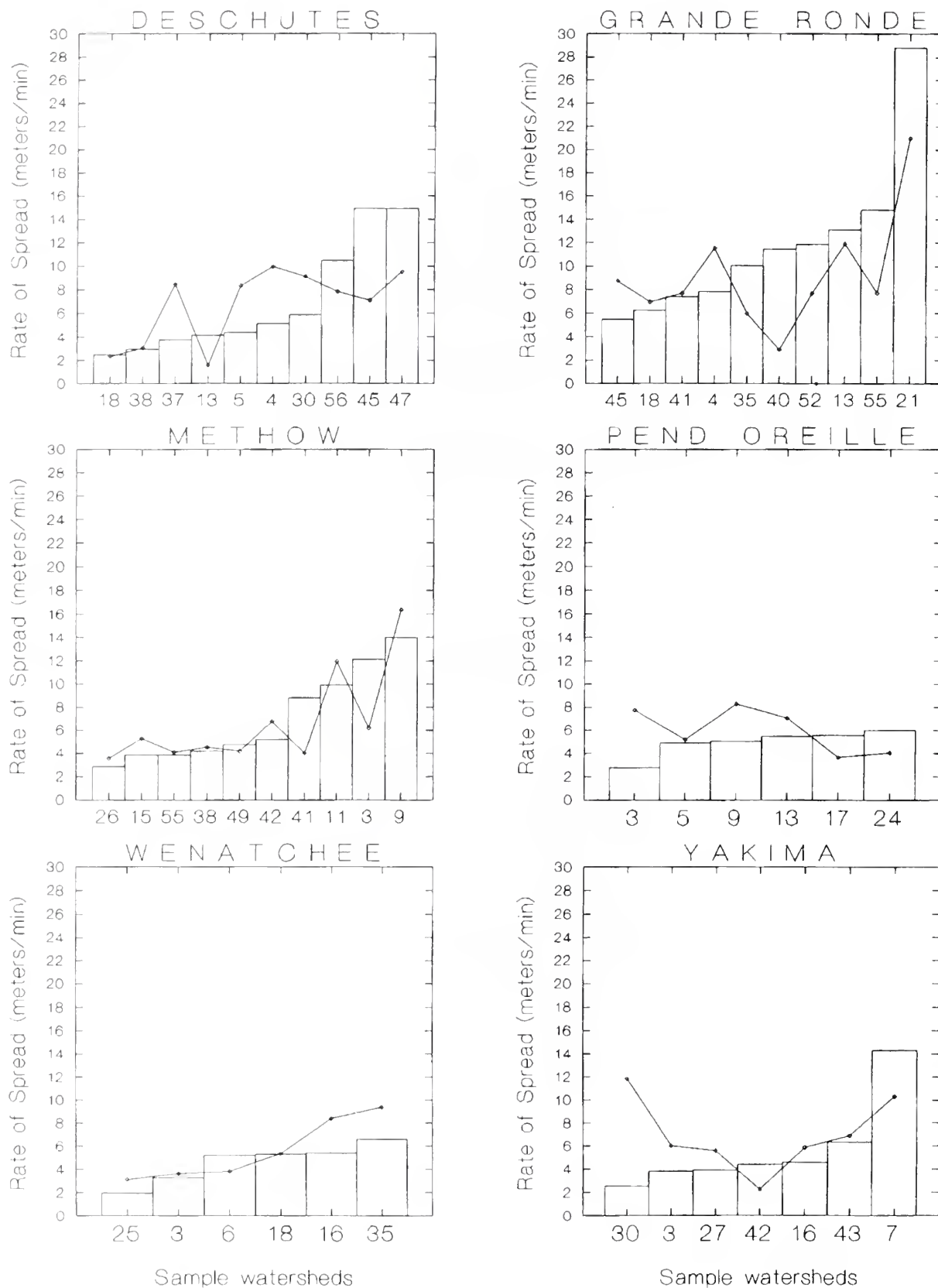


Figure 35—Comparison of historical (*bars*) and current (*line*) potential rates of fire spread by sample watersheds on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

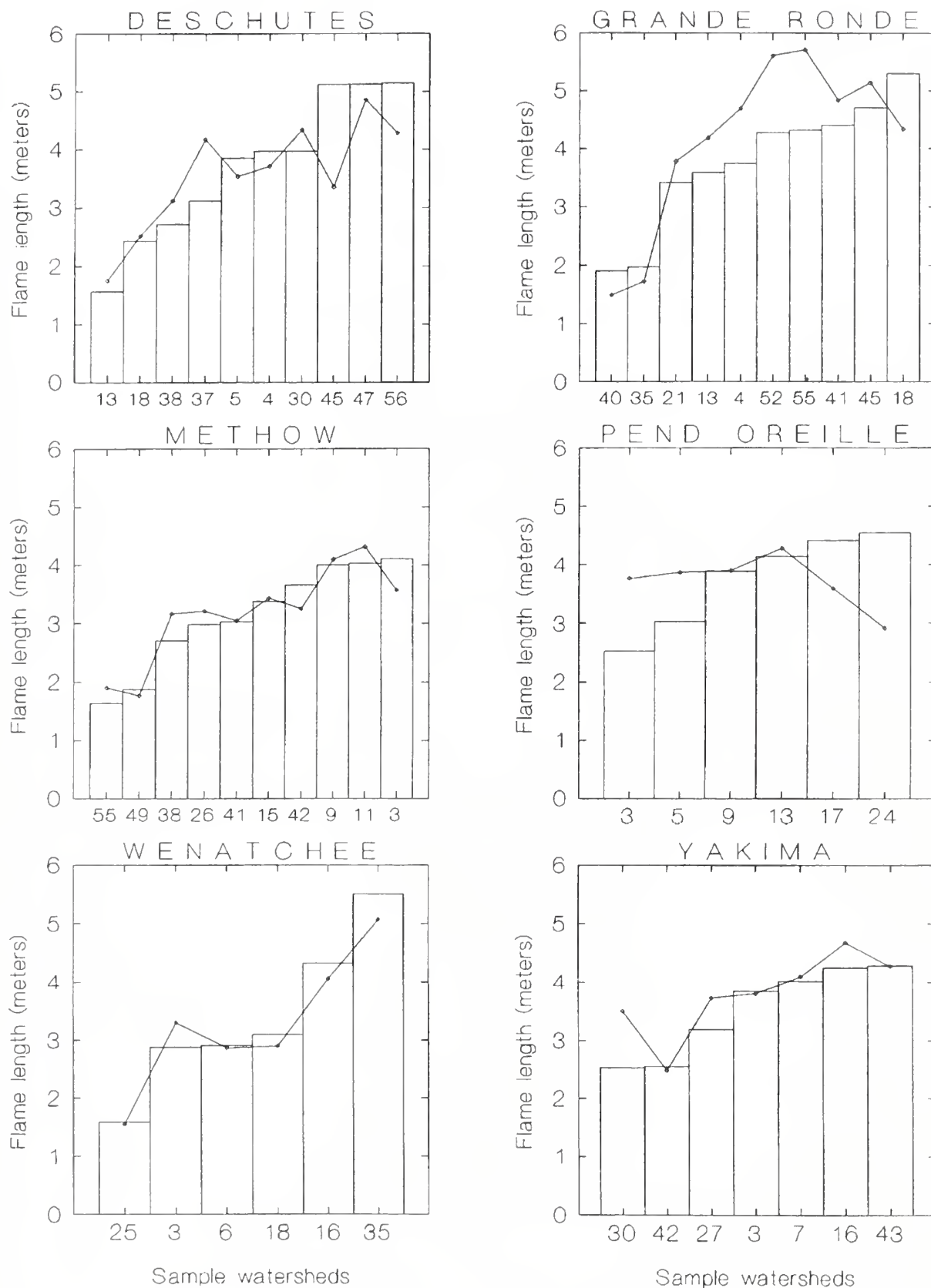


Figure 36—Comparison of historical (*bars*) and current (*line*) potential flame lengths by sample watersheds on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

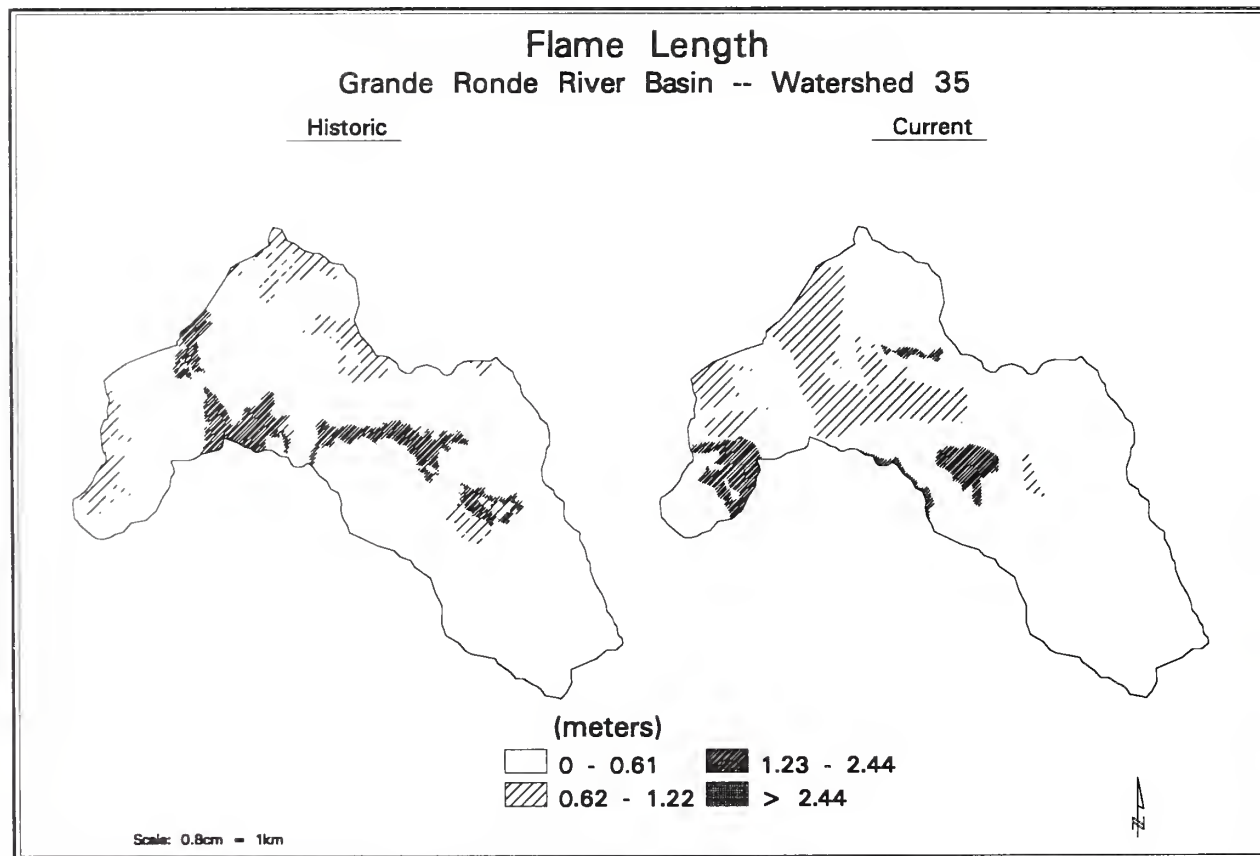
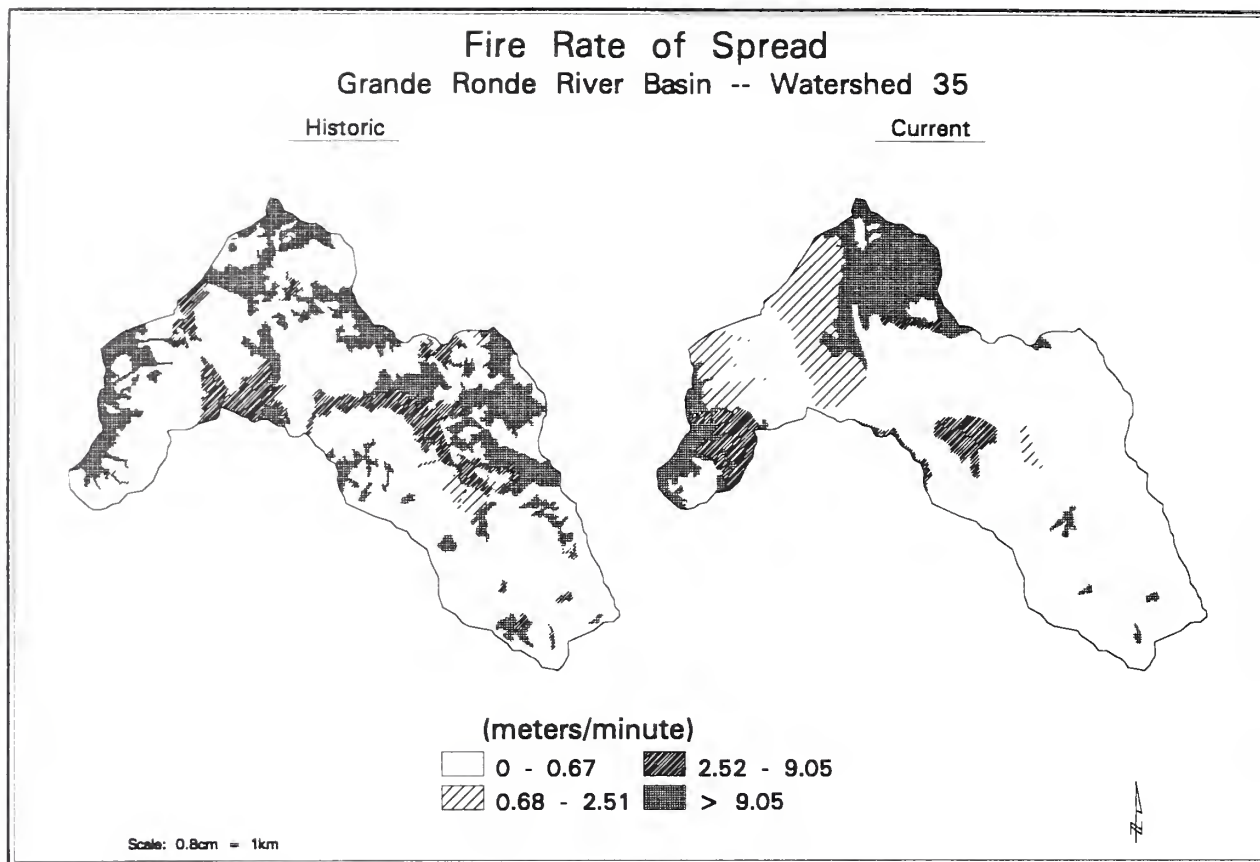


Figure 37—Historical and current patterns of potential rate of fire spread and flame length for sample watershed 35 in the Eagle Cap Wilderness of the Grande Ronde River Basin, Oregon.

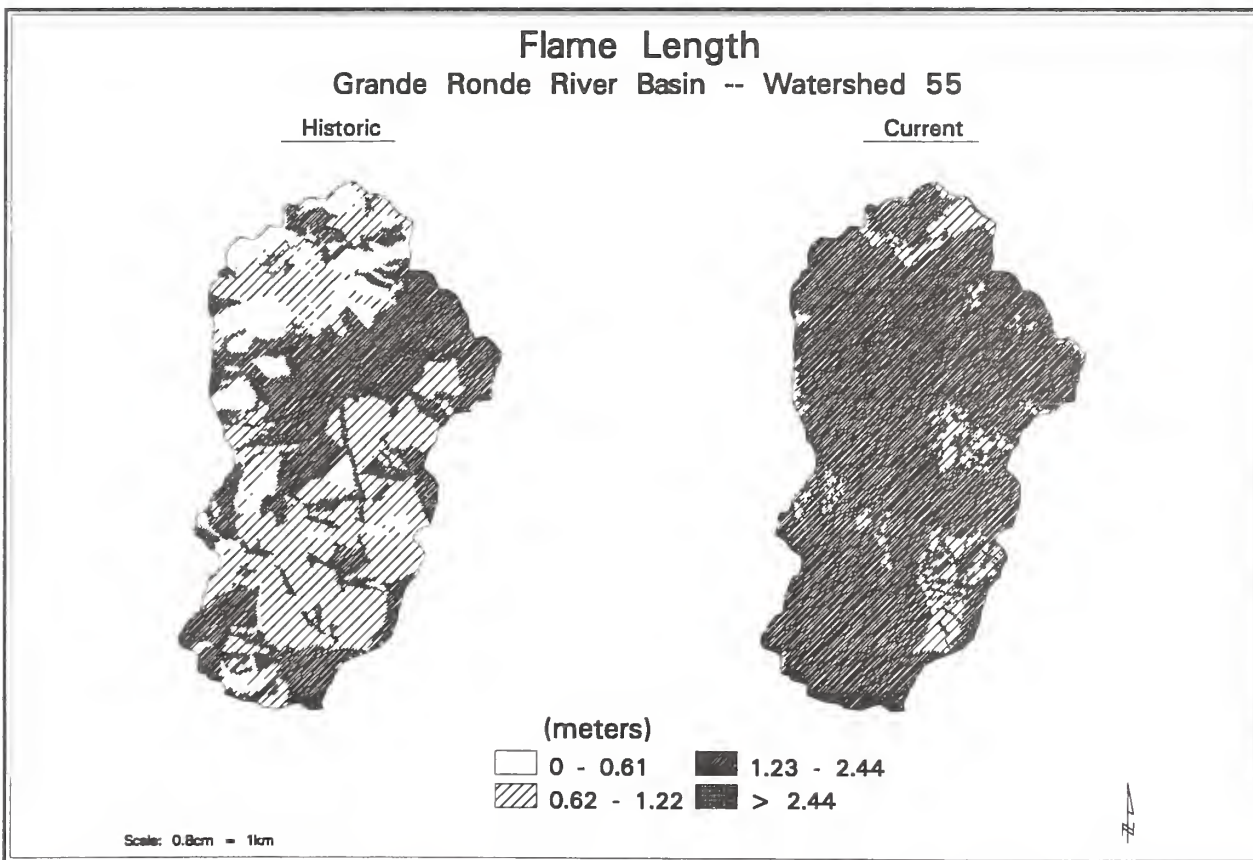
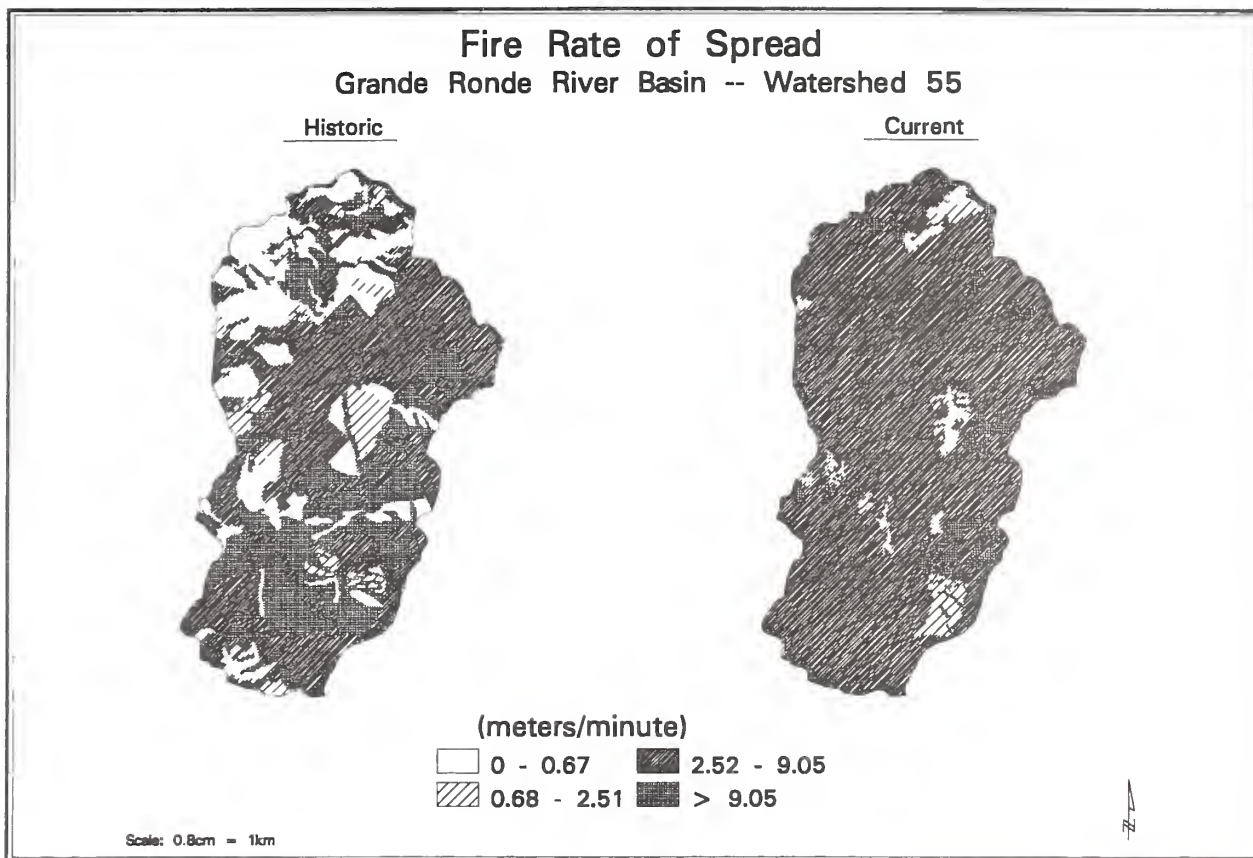


Figure 38—Historical and current patterns of potential rate of fire spread and flame length for sample watershed 55 in the Wenaha-Tucanon Wilderness of the Grande Ronde River Basin, Oregon.

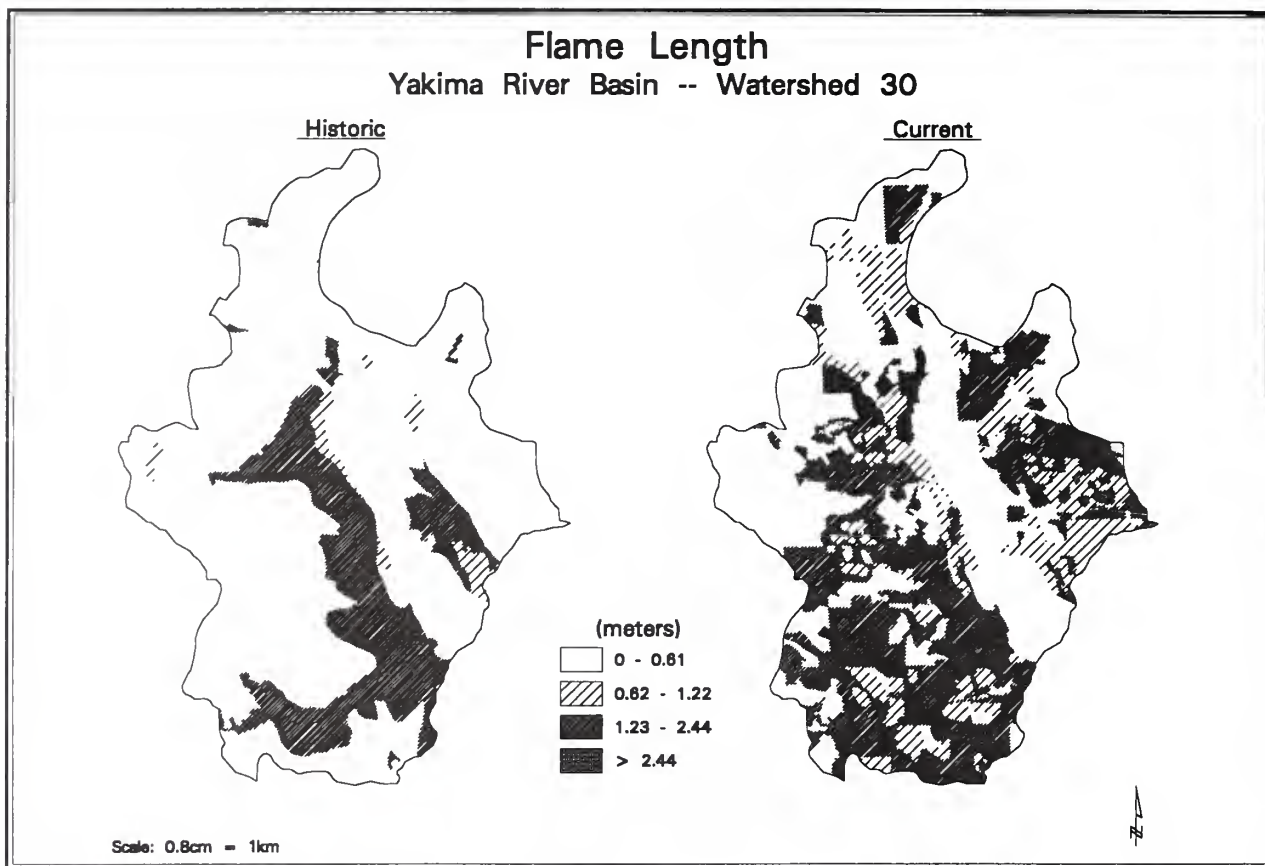


Figure 39—Historical and current patterns of potential rate of fire spread and flame length for sample watershed 30 in the Yakima River Basin, Washington.

Table 3—Ranges and direction of change from historical to current periods in estimates of fire rate of spread (meters/minute), flame length (meters), and percentage of sample watersheds in Washington and Oregon river basins where rate of spread and flame length increased

Variable	River basin					
	Deschutes	Grande Ronde	Methow	Pend Oreille	Wenatchee	Yakima
Change in rate of spread						
Maximum (+ change)	1.60	1.24	0.80	1.67	0.99	3.12
Minimum (- change)	-2.61	-2.85	-1.99	-0.66	-0.46	-1.33
Change in flame length						
Maximum (+ change)	0.32	0.43	0.12	0.38	0.13	0.30
Minimum (- change)	-0.54	-0.29	-0.16	-0.50	-0.13	-0.02
Percentage increase						
Rate of spread	50.00	40.00	70.00	66.67	83.33	71.43
Flame length	50.00	70.00	60.00	50.00	16.67	57.14

Table 4—Percentage of sample watersheds in eastern Washington and Oregon river basins during historical and current periods with rates of spread (ROS) above 2.5 m/min and flame lengths (FL) above 2.3 m, where initial control efforts would be difficult

Variable	River basin					
	Deschutes	Grande Ronde	Methow	Pend Oreille	Wenatchee	Yakima
Rate of spread						
Current	50.0	60.0	20.0	33.0	33.0	28.5
Historical	30.0	70.0	40.0	0.0	0.0	14.3
Flame length						
Current	0.0	0.0	0.0	0.0	0.0	0.0
Historical	0.0	0.0	0.0	0.0	0.0	0.0
N of sample watersheds	10	10	10	6	6	7

Table 5—Correlation coefficients of rate of spread and flame length with current percentage area not logged and logged in sample watersheds in eastern Washington and Oregon river basins

Variable	River Basin					
	Deschutes	Grande Ronde	Methow	Pend Oreille	Wenatchee	Yakima
Rate of spread						
No historical logging visible	-0.72	0.11	-0.53	-0.98	-0.95	-0.55
Historical logging (total)	0.72	-0.11	0.54	0.98	0.95	0.55
Harvest types						
Clearcut/shelterwood	0.70	0.05	0.79	0.96	0.94	0.67
Selective	0.60	-0.14	0.41	0.91	0.95	0.05
Thinning	0.45	-0.05	-0.12	0.48	0.65	0.59
Patch clearcut	-0.38	0.01	0.29	0.67	0.92	-0.20
Flame length						
No historical logging visible	-0.79	-0.22	-0.76	-0.61	-0.77	-0.18
Historical logging (total)	0.79	0.22	0.77	0.63	0.78	0.16
Harvest types						
Clearcut/shelterwood	0.84	0.38	0.63	0.61	0.73	-0.16
Selective	0.57	0.12	0.69	0.62	0.80	0.36
Thinning	0.59	0.25	0.21	0.04	0.52	0.27
Patch clearcut	-0.32	0.28	0.17	0.57	0.77	-0.03

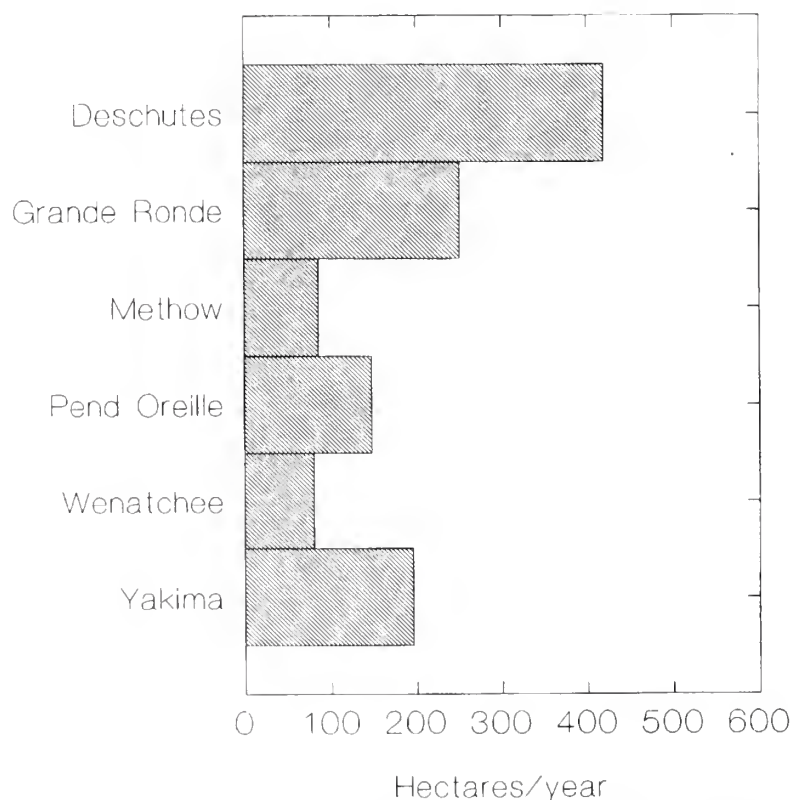


Figure 40—Average area prescription burned during 1990 and 1991 in sample watersheds of river basins in eastern Washington and Oregon.

Smoke Production

Area burned—Average area burned with prescribed fire for the sample watersheds within each basin during 1990 and 1991 is shown in figure 40. No prescribed burning had occurred in sample watersheds prior to the year they were mapped for historical composition because prescribed burning did not begin in eastern Oregon and eastern Washington until about 1970. Current prescribed burning ranged from 420 ha/year in the Deschutes River basin, to 80 ha in the Wenatchee River basin. One reason the Wenatchee River basin has a smaller burned area is because many of the sample watersheds are in wilderness where no fires have been prescribed. In the future, the area receiving prescription burning is expected to be about three times these current values.

Because of time constraints, wildfire data were analyzed only for Grande Ronde watersheds 35 and 55, and Yakima watershed 30 for 1970 and 1988 (fig. 41). In watershed 35, 10 fires were reported, for a total of 4988 ha burned, and an annual average of 149 ha. Included in this figure are two large fires of 3780 ha and 947 ha. In watershed 55, 24 fires burned 14 ha during the same period, averaging 0.8 ha a year; none of these fires was larger than 2 ha. Finally, in the Yakima River basin watershed 30, 33 fires burned 3298 ha, an average of 183 ha annually. One fire burned 3278 ha in this watershed, however.

Fuel consumption—Potential prescribed fire fuel consumption averages for the six river basins ranged from 37.3 mg/ha on the Deschutes River basin (current) to 30.9 mg/ha on the Methow River basin (historical) (fig. 42). The Grande Ronde River basin and Methow River basins were the only areas with significant differences in fuel consumption between the historical and current periods. Wildfire fuel consumption averages were about double those of prescribed fire, ranging from 57.3 mg/ha on the Deschutes River basin (current) and Yakima basin (historical) to 48.1 mg/ha on the Methow River basin (historical) (fig. 43). For wildfire fuel consumption, the Wenatchee River basin was the only one tested that displayed a significant difference in historical and current wildfire fuel consumption (figs. 42, 43).

Emission factors (PM₁₀)—Average emission factors for the river basins ranged from 10.3 g/kg of fuel for prescribed fire in the Grande Ronde basin (historical), to 14.6 g/kg for wildfire in the Pend Oreille basin (historical) (figs. 44, 45). Current emission factors for prescribed fire were higher ($P \leq 0.10$) for the Grande Ronde, but lower ($P \leq 0.10$) for the Deschutes and Pend Oreille River basins, compared with historical emission factors. Current wildfire emission factors were higher ($P \leq 0.10$) than in the past for the Grande Ronde, Methow, and Yakima basins, but they were lower ($P \leq 0.10$) for the Deschutes and Pend Oreille River basins.

Smoke production (PM₁₀)—If fuel consumption is multiplied by the PM₁₀ emission factor, the potential amount of smoke produced per hectare burned can be calculated. Prescribed-fire smoke production ranged from 409 kg/ha in the Deschutes River basin (historical) to 323.6 kg/ha in the Grande Ronde River basin (historical) (fig. 46). The greatest difference between historical and current results for prescribed fires was in the Grande Ronde River basin, which exhibited an increase of 48.3 kg/ha. The Methow was the only other river basin to display a significant difference in smoke production for prescribed fires.

Although two of the six river basins exhibited significant differences between historical and current wildfire emissions, the differences were small (fig. 47). Many sample watersheds within a river basin displayed large changes from the past, however. The Grande Ronde River Basin, for example, displayed an average increase of 90 kg/ha in smoke production. Potential smoke production in sample watershed 55, however, increased 258 kg/ha and a decrease of 98 kg/ha occurred in sample watershed 35 (figs. 48, 49, 50). Likewise, in the Yakima River basin, potential smoke production decreased slightly by 23 kg/ha but watershed 30 in the same basin had a 159 kg/ha decrease (figs. 48, 51).

Wildfire smoke production rates were twice those of prescribed fire, ranging from 799.2 kg/ha on the Deschutes River basin (current) to 622.1 kg/ha on the Grande Ronde River basin (historical) (fig. 47, appendix C). The greatest difference between historical and current values was an increase of 89.7 kg/ha in the Grande Ronde River basin. The Deschutes and Wenatchee River basins also displayed significant differences in wildfire smoke production, but the changes were smaller. If a 20,000-ha wildfire occurred in the Grande Ronde River basin today, about 1.8 million more kilograms of smoke would result than if the fire had occurred 50 years ago—an increase of 13-percent.

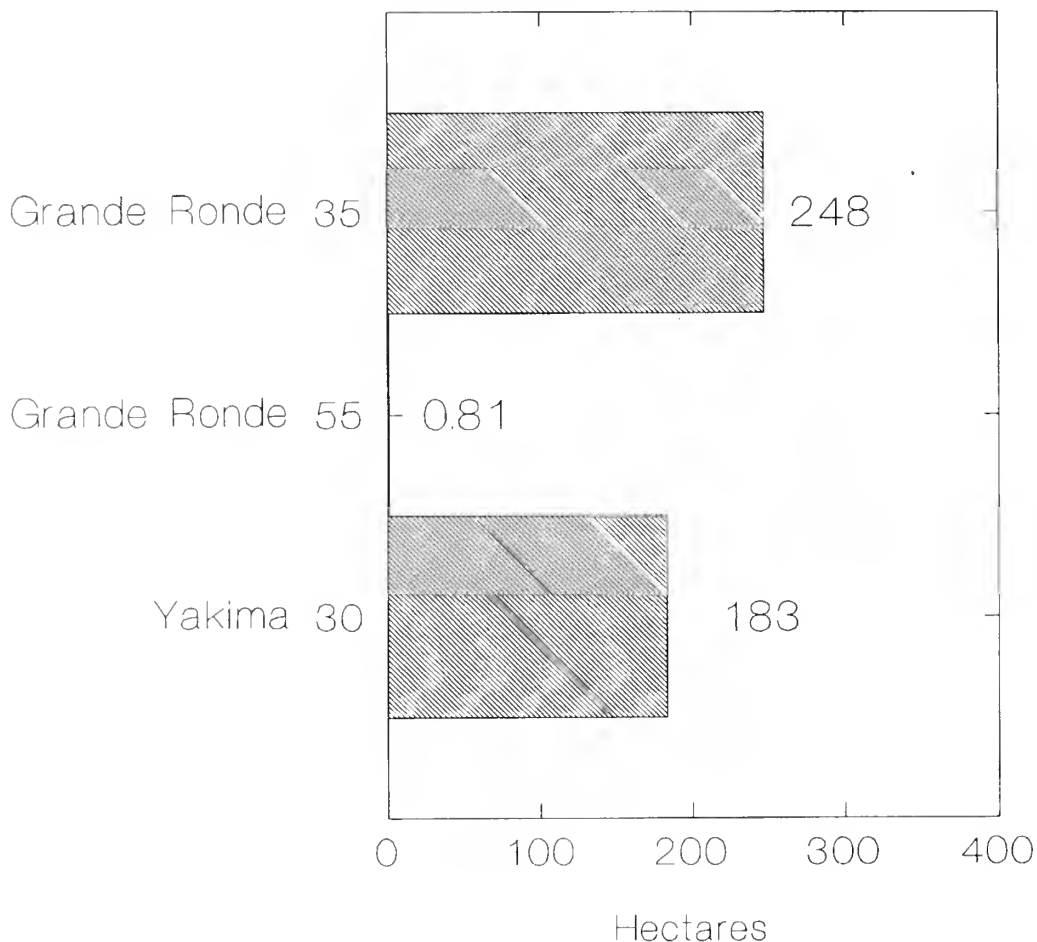


Figure 41 — Average area burned in wildfires from 1970 to 1988 for selected sample watersheds in river basins in eastern Washington and Oregon.

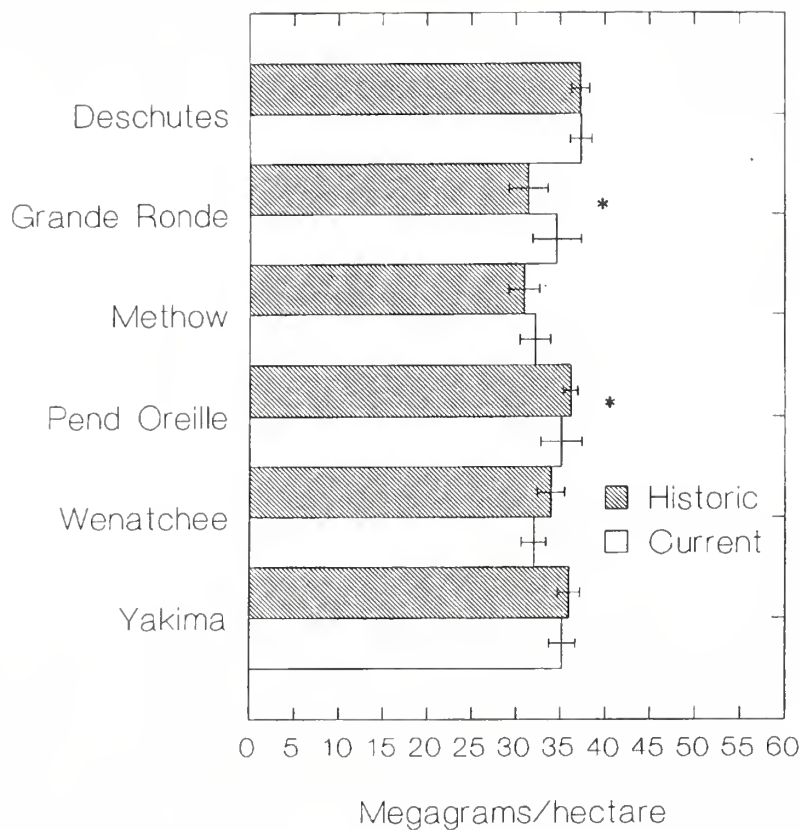


Figure 42—Historical and current prescribed-fire fuel consumption averages on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

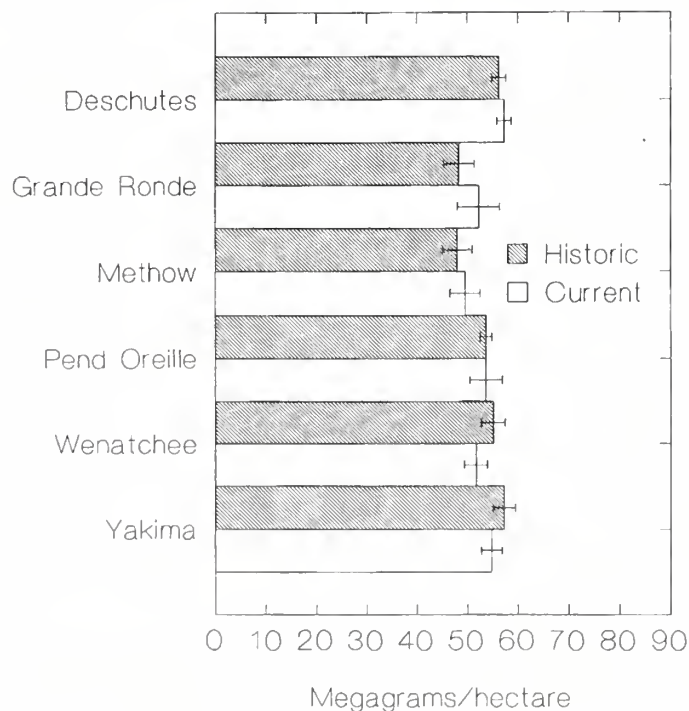


Figure 43—Historical and current wildfire fuel consumption averages on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

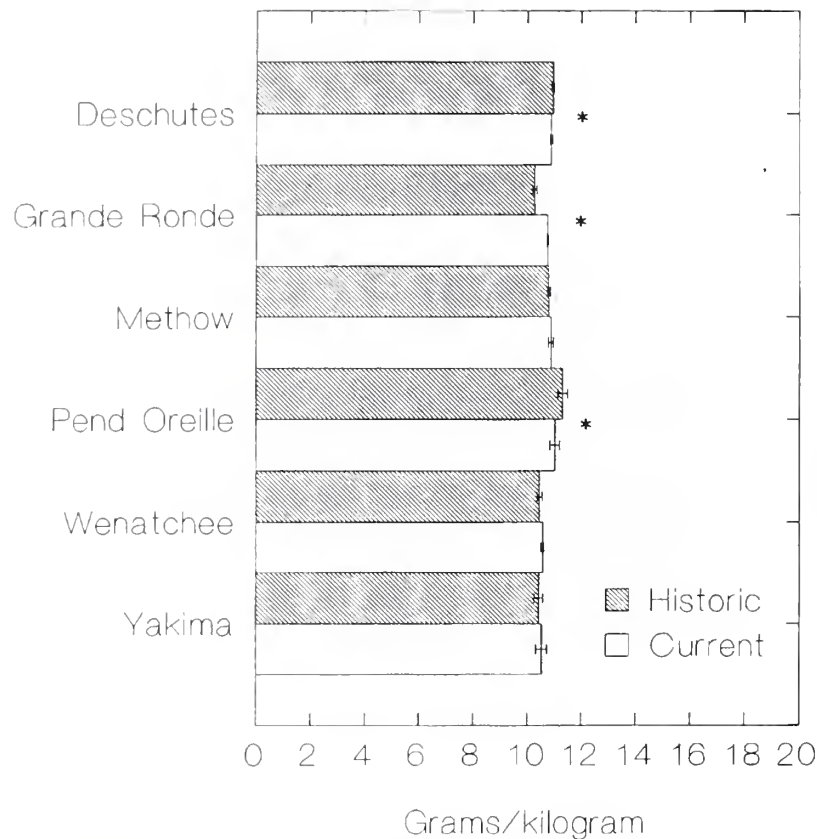


Figure 44—Historical and current prescribed-fire emission factors on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

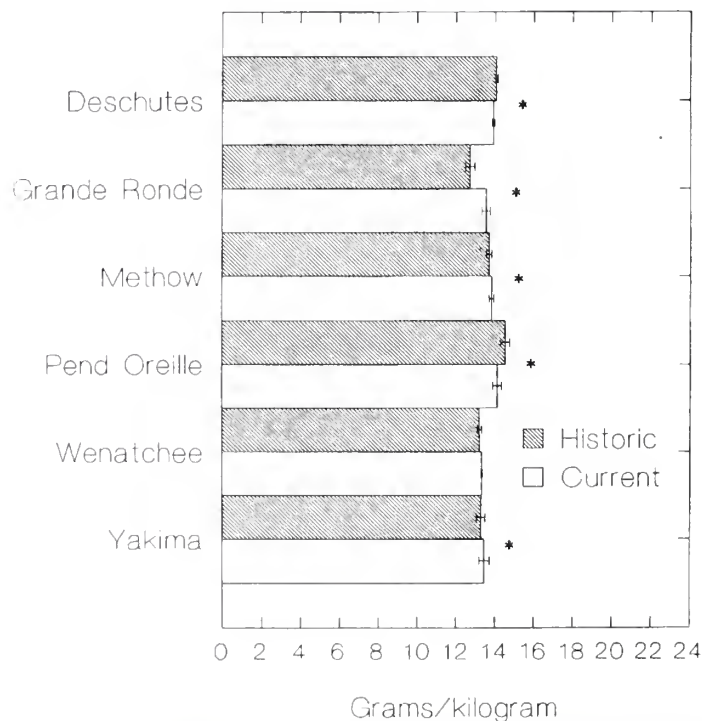


Figure 45—Historical and current wildfire emission factors on lands within National Forest boundaries in river basins of eastern Oregon and Washington.

Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

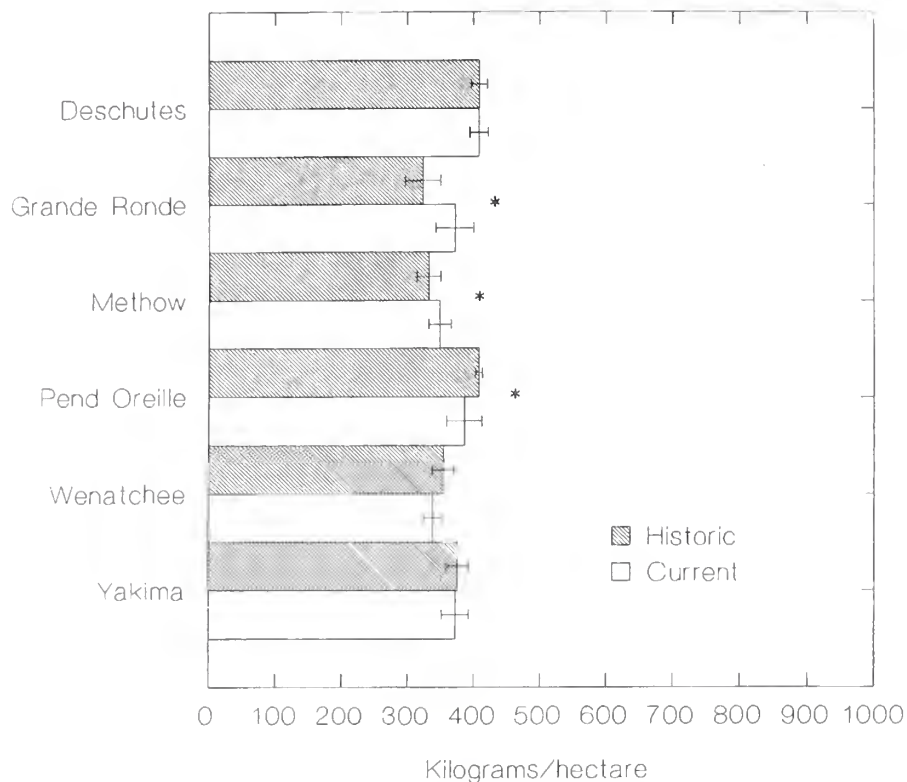


Figure 46—Historical and current average prescribed-fire smoke production on lands within National Forest boundaries in river basins of eastern Oregon and Washington.
 Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

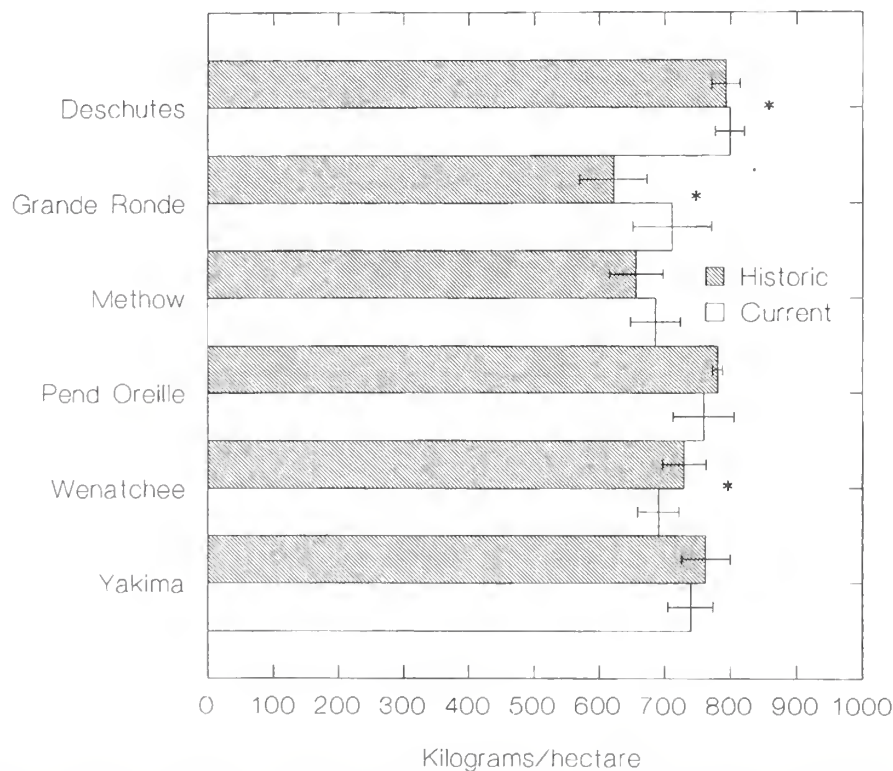


Figure 47—Historical and current average wildfire smoke production on lands within National Forest boundaries in river basins of eastern Oregon and Washington.
 Error bars are the standard error of the stratified mean estimate. Asterisks indicate significant differences ($P \leq 0.10$) between historical and current basin conditions.

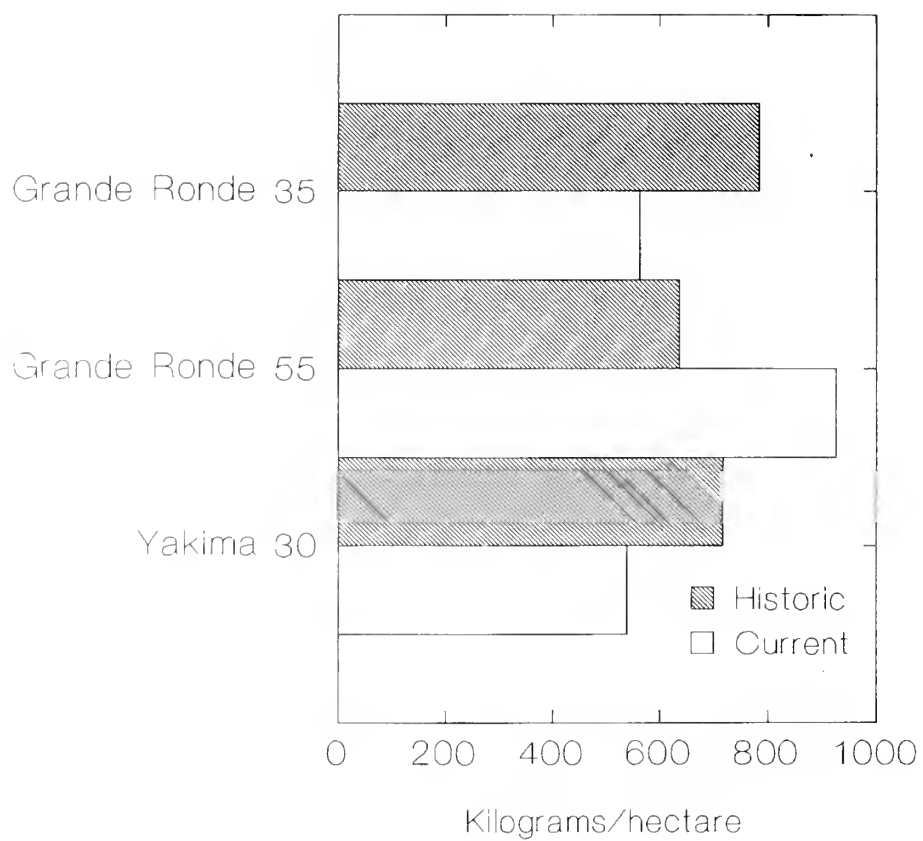


Figure 48—Historical and current average wildfire smoke production for selected watersheds in the Grande Ronde and Yakima river basins of eastern Oregon and Washington.

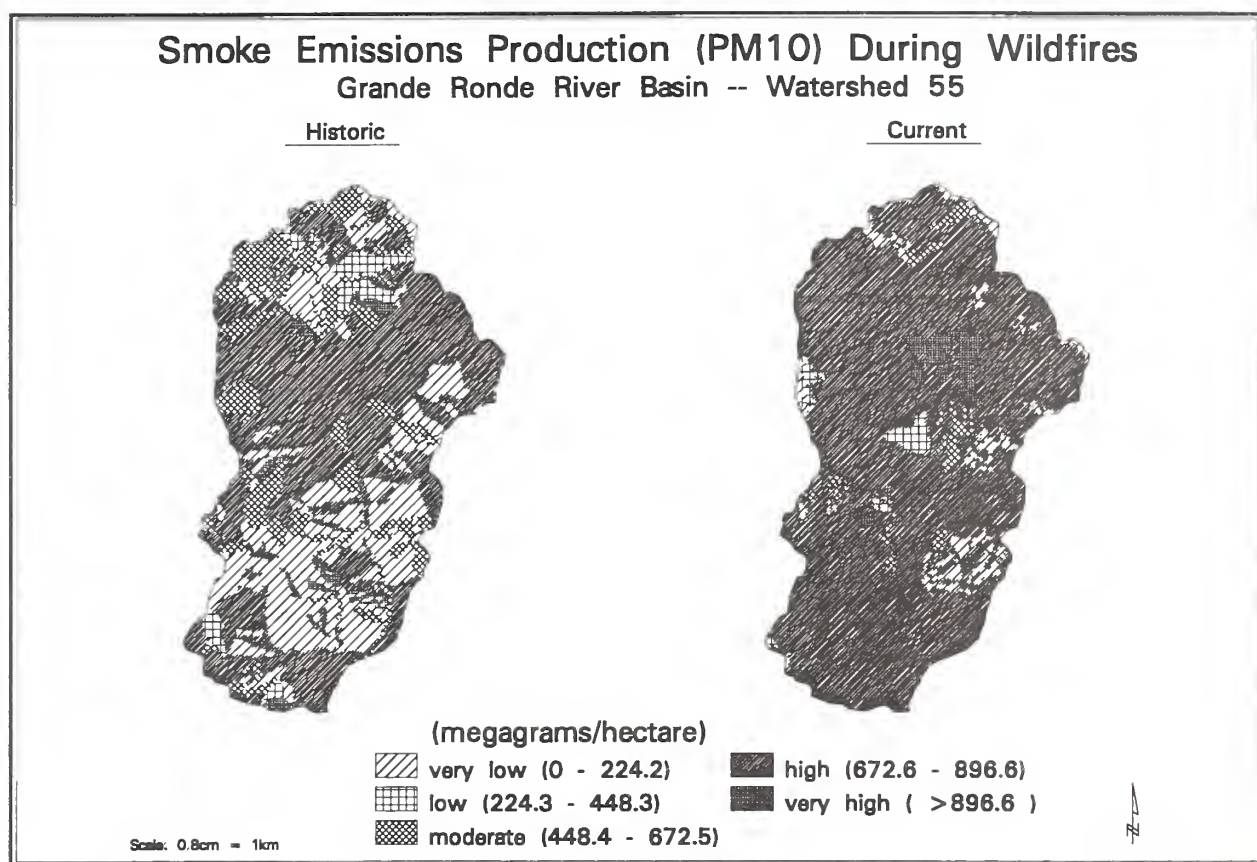


Figure 49—Historical and current wildfire smoke production maps for watershed 55 in the Grande Ronde River basin, eastern Oregon.

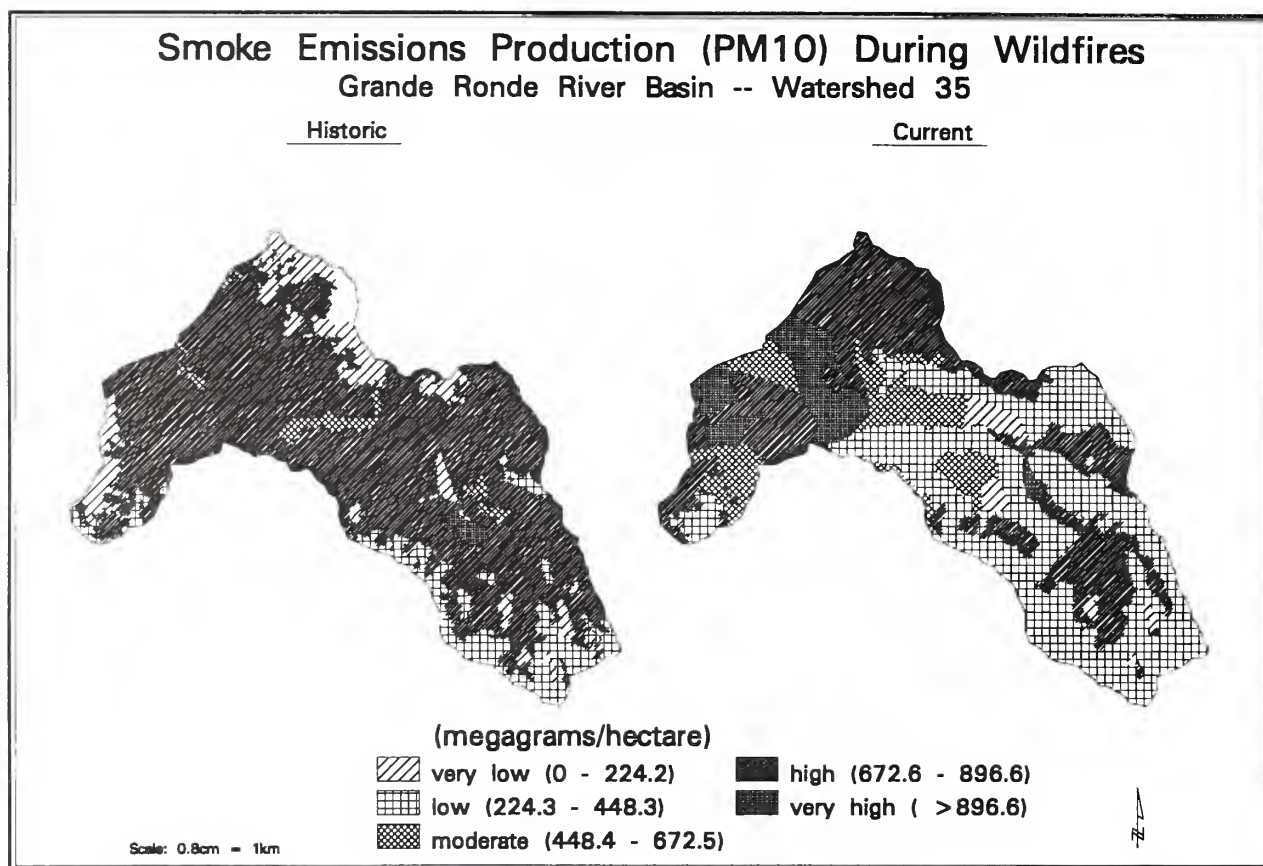


Figure 50—Historical and current wildfire smoke production maps for watershed 35 in the Grande Ronde River basin, eastern Oregon.

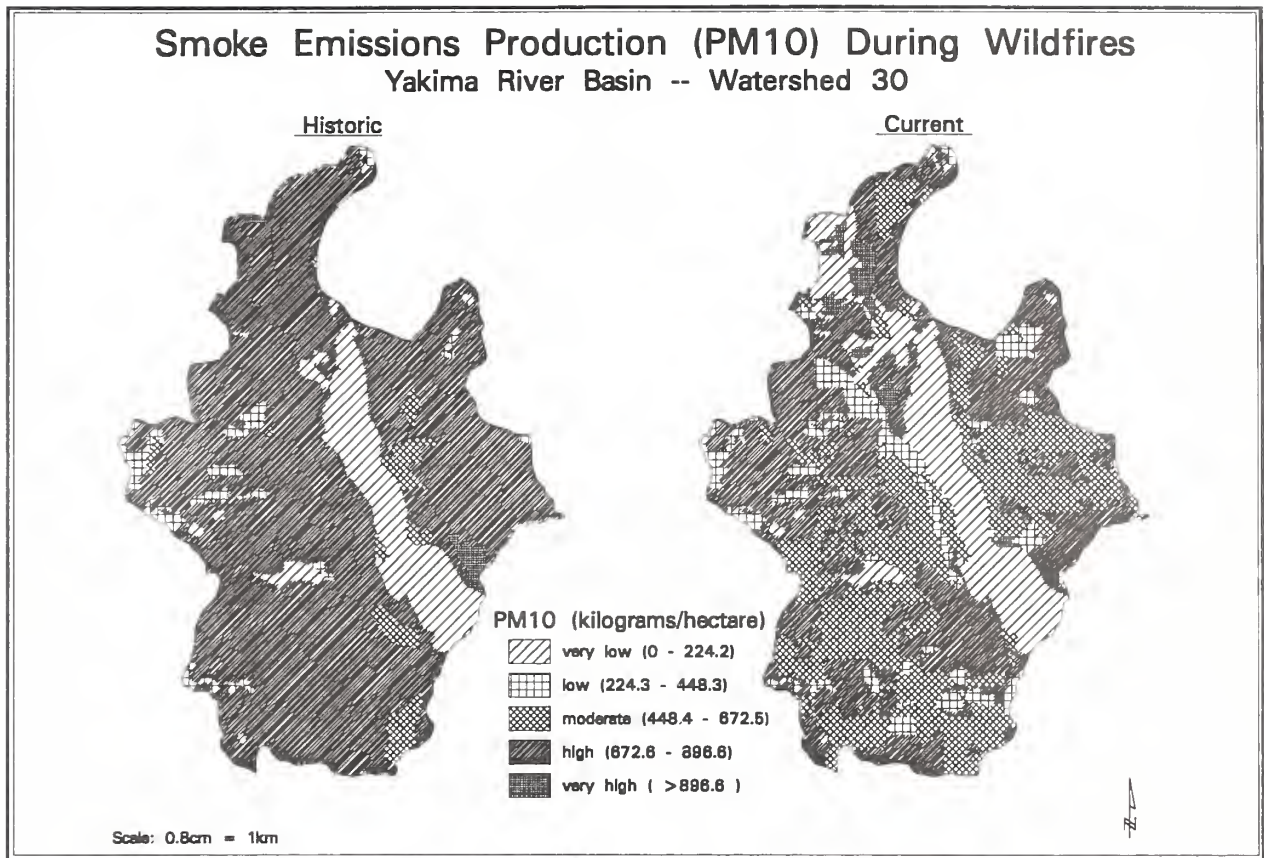


Figure 51—Historical and current wildfire smoke production maps for watershed 30 in the Yakima River basin, eastern Washington.

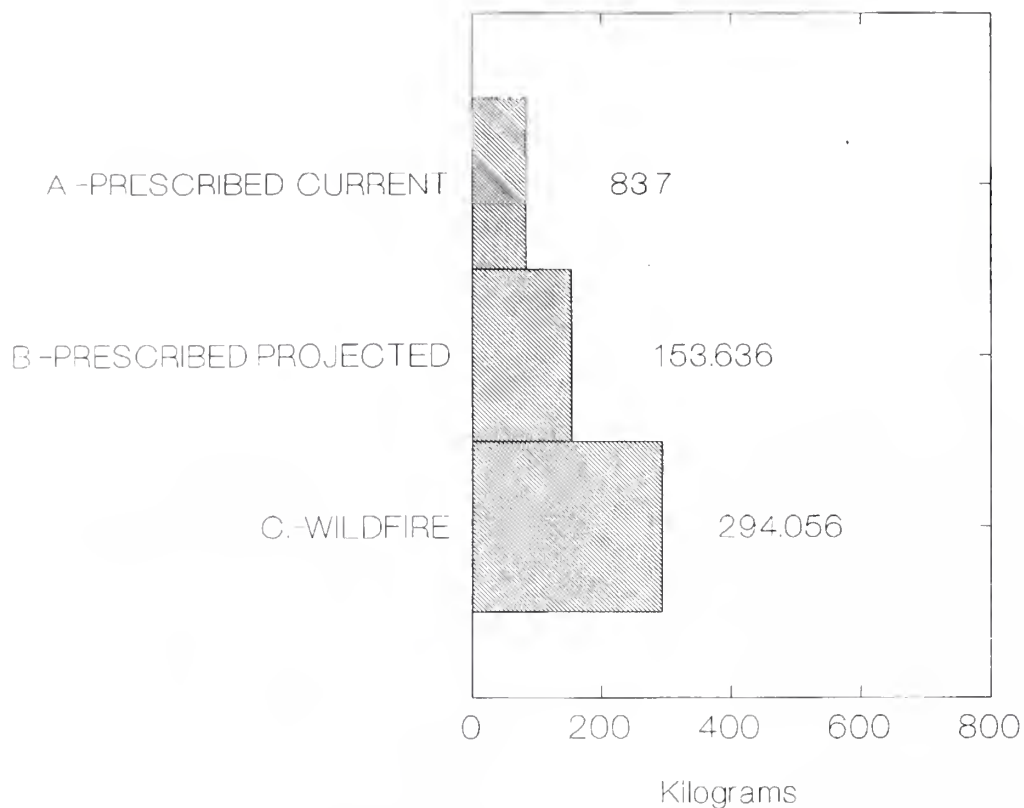


Figure 52—Comparison of total emissions produced under different alternatives in watershed 4 in the Grande Ronde basin, Oregon: A, current prescribed burning program continues; B, watershed is treated with prescribed fire periodically over the next 15 years, and C, wildfire occurs periodically over the next 15 years.

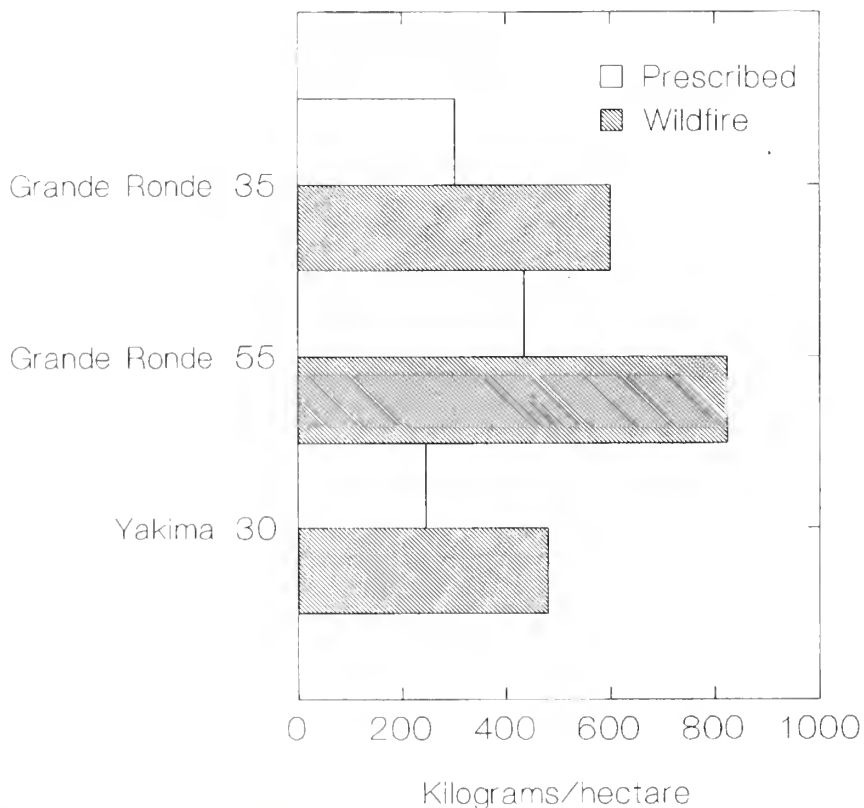


Figure 53—Average current prescribed fire and wildfire smoke production for selected sample watersheds in the Grande Ronde River and Yakima River basins, eastern Oregon and Washington.

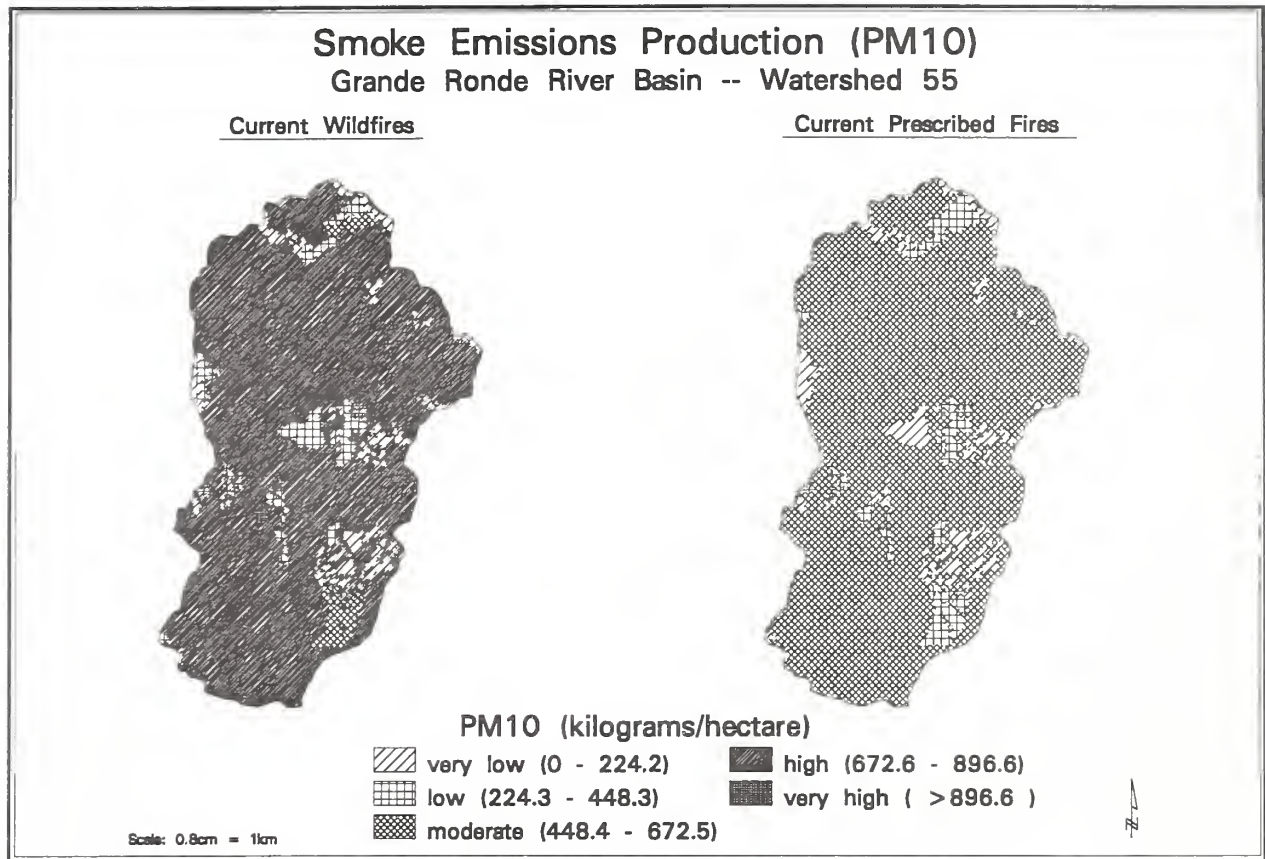


Figure 54—Potential smoke emissions for wildfire and prescribed fire occurrence in sample watershed 55 in the Grande Ronde River basin, eastern Oregon.

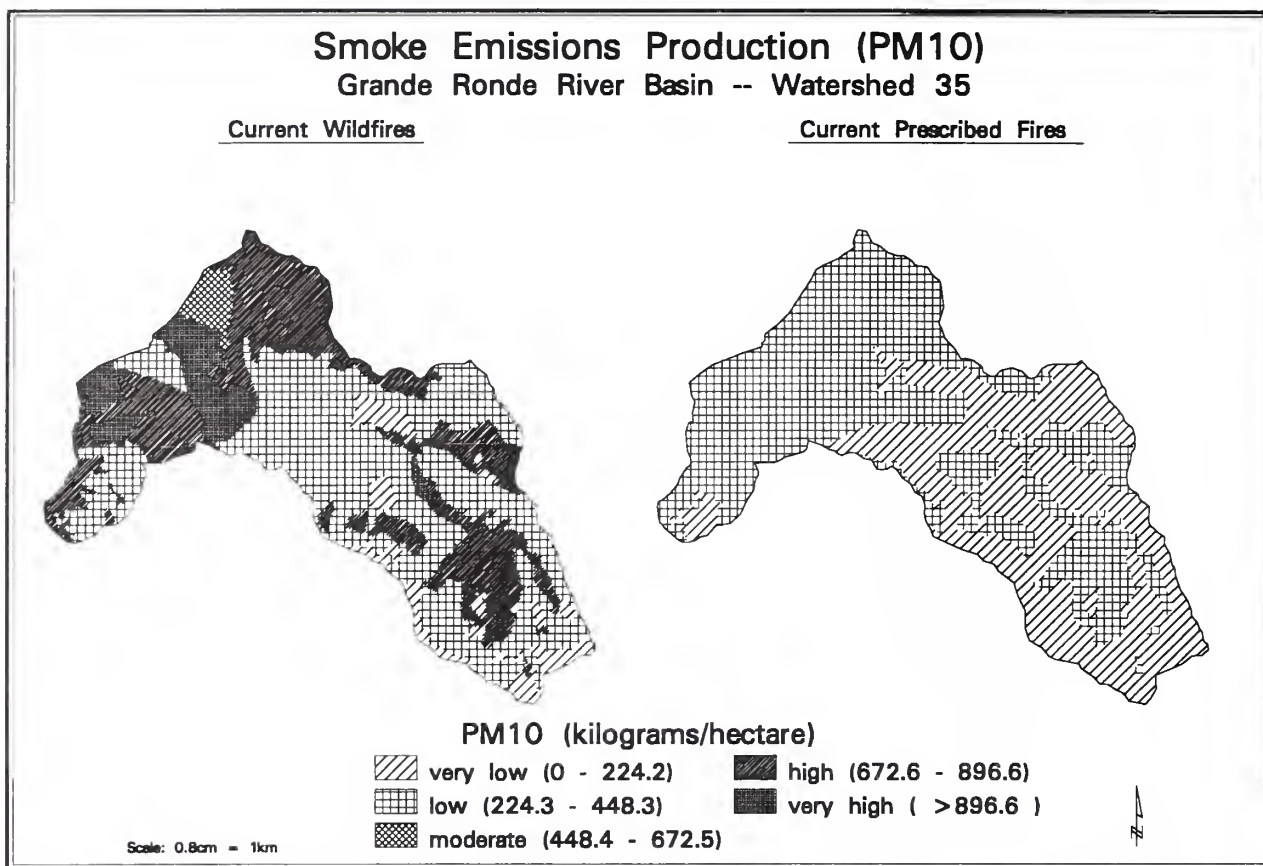


Figure 55—Potential smoke emissions for wildfire and prescribed fire occurrence in sample watershed 35 in the Grande Ronde River basin, eastern Oregon.

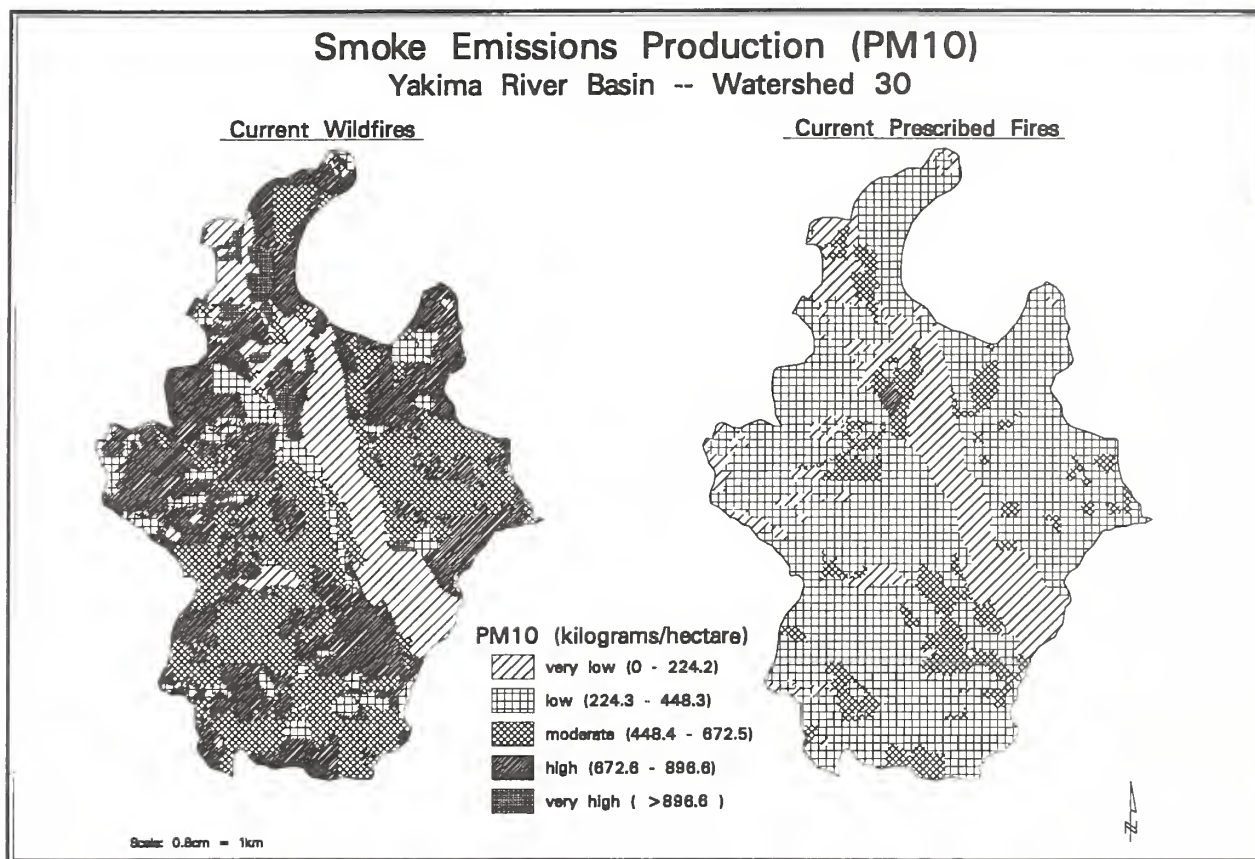


Figure 56—Potential smoke emissions for wildfire and prescribed fire occurrence in sample watershed 30 in the Yakima River basin, eastern Washington.

DISCUSSION

Measuring Ecosystem Change

Detection of significant change in river basins would require that change in a variable be similar among sample watersheds and sample strata. In hindsight, this expectation was unrealistic. Vegetation, insect and disease hazard, fire behavior, and smoke production data were developed from a population of sample watersheds that have different management and disturbance histories, and different vegetative composition and structural characteristics. Because the data were based on vegetation composition and structure, past histories of the sample watersheds were often responsible for much of the underlying variability.

Although the two periods, historical and current, were reasonably fixed within a river basin, obviously the historical landscape settings (starting points), which were our basis for detecting change, varied greatly among the sample watersheds. For example, some sample watersheds had evidence of large wildfires in the past and other watersheds, with reasonably similar climates and geology, exhibited little evidence of fires during the same period (figs. 37, 38). A large fire sets a sample watershed into a successional stage that is substantially different from the successional stage of the watershed that didn't burn; consequently, their starting points and patterns from a landscape perspective were quite different.

No significant difference of many variables between historical and current river basins could be related to factors other than site-specific fire histories. Ecologically diverse systems have high natural variability within and among watersheds and strata. Between six and ten watersheds were sampled within each river basin, with one or two sample watersheds per stratum. Even at 15-percent of the area, this sample size is still relatively small considering geographic extent and spatial heterogeneity of the different river basins. Seventy-two additional sample watersheds have been photo-interpreted and data-entered to bolster the sample size to 26-percent within each river basin. They will be included in subsequent analyses.

Land management objectives also differed considerably among sample watersheds—from unlogged wilderness to areas intensively managed with more than 50-percent of the area logged. The amount and type of management activities are difficult factors to control in designing landscape-scale studies. Landscapes managed primarily for wilderness are expected to change at different rates and in different directions, than ones managed more intensively for forest products. Any sample of watersheds within river basins with multiple-use land management objectives would be expected to have high variability. One approach in subsequent analyses with more sample watersheds will be to compare wilderness-dominated landscapes with intensively managed ones. Wilderness areas tend to be in middle and high-elevation ecosystems, however, and harvesting and other management activities have been more concentrated at lower and middle elevations. Some comparisons may not be practical if vegetation composition, structure, and other ecosystem attributes differ significantly between wilderness and nonwilderness areas. Furthermore, the effects of management activities such as fire suppression, that are more subtle than those produced by tree harvesting, could also differ significantly among sample watersheds.

The quality of the aerial photographs available to photo interpreters might be another source of variation between historical and current conditions. Certain attributes on the black and white photographs taken 35 to 50 years ago, such as snags and understory composition, were somewhat difficult to distinguish, and some photo sets were taken in different years under different conditions, adding another possible source of variation. These photos and the data interpreted from them, however, were the best available.

Given the relatively small sample of watersheds and the high variability among watersheds, fewer significant differences or lower power to detect differences would be expected than with a larger sample. Therefore, significant changes we have described likely are conservative.

Vegetation

Composition and structure—Many of the predicted changes in composition and structure of eastside forest vegetation associated with fire suppression were largely borne out by the data. A causal link is difficult to establish, however, because the amount of fire suppression was not directly measurable or quantifiable. Increases in forest cover in the Deschutes, Grande Ronde, and Pend Oreille River basins suggested that effective fire suppression had resulted in a forest growing on what were previously bare or grassy areas maintained by fire or in logged areas. This encroachment on bare ground may have occurred in the Deschutes, Grande Ronde, and Pend Oreille basins, where bare ground decreased, but change in the Pend Oreille basin was likely the result of revegetation of extensive areas burned before 1930. We might also expect grass/forb cover to decrease with fire suppression, particularly where grazing reduces grass cover, vigor, and flashy litter fuel (Agee 1993). We did not find this decrease in two of three basins that exhibited increased forest cover: grass/forb cover increased in the Deschutes and Pend Oreille basins, but decreased in the Grande Ronde. Further analysis of fire and grazing histories is necessary to firmly establish the causes for changes in forest cover.

Predicted shifts from early seral species, such as ponderosa pine, to middle or late seral species, such as Douglas-fir and grand fir, with fire suppression and harvest of early-seral overstory dominants (Agee 1993, Caraher and others 1992, Gast and others 1991, Hessburg and others 1993) were shown in some areas. Fire suppression may be a partial cause of this change, but we cannot directly test this hypothesis. Moreover, examination of watersheds in wilderness or without visible logging, where fire suppression alone might be the dominant factor, exhibited very different responses within basins. For example, Grande Ronde watersheds 13 and 21 had no visible logging during the two mapping periods, but they exhibited very large increases (20-30-percent total area) in ponderosa pine cover with concurrent decreases in Douglas-fir cover. In contrast, Grande Ronde watersheds in the Wenaha-Tucanón wilderness (52, 55) exhibited marked decreases (35-50-percent of the area) in ponderosa pine cover and increases in Douglas-fir cover. A preliminary analysis of all watersheds for the effects of logging exhibited that ponderosa pine cover declined as the area of selection logging increased from 10 to 30-percent of the landscape ($r = -0.55$). Such generalizations for the entire eastside are risky, however, because variability among watersheds was high. More detailed analysis of the complete set of watershed data may address this question more adequately.

The range of variability in ecosystem attributes is an important element of the ecosystem management paradigm (Risbrudt 1992). Ranges of variation from our work in the Grande Ronde can be compared to the estimates by Caraher and others (1992) for the marine physiographic zone of the Blue Mountains ecoregion. Caraher estimated the historical ranges of natural variability of the Douglas-fir and true-fir early-seral stage as 20 to 40-percent of forest area, mature parklike stands as 20 to 40-percent, and late-seral multistory stages as 50 to 80-percent of the forested landscape.

We used our standard error of the stratified mean as an estimate of variability that includes 68-percent of the sample means at the basin scale. We estimated the range of variation that occurred about 40 years ago to be 20 to 30-percent of the basin area in early-seral stages (seedling-sapling-pole class [SSP]), similar to an estimate by Caraher and others (1992); in mature parklike structure, 10 to 25-percent, which is lower than Caraher's estimate (fig. 14). Our estimates include all forest types, including subalpine fir. Estimation of the range of late-seral multistory forest would require combining our young, mature, and old-forest categories, so our data are not directly comparable for this category.

Caraher and others (1992) estimated the current area of early-seral forest was less than 20-percent of the forested landscape; we found the SSP class accounted for about 10-percent of the basin area. Likewise, they found that parklike stands were below the range of historical variation, mostly about 10-percent of the forested landscape; we found these stands accounted for a much smaller 1-percent of the total forest area in the Grande Ronde basin.

Caraher and others (1992) also estimated the historical range of variation and current area of high-density, low-vigor ponderosa pine and lodgepole pine stands in the Grande Ronde. High-density ponderosa pine stands were estimated to have been from 0 to 10-percent and lodgepole pine stands from 20 to 30-percent of historical forest landscapes. Current estimates of area for ponderosa pine are above the range of variation at 10 to 30-percent total area, but lodgepole pine is estimated to be within the 20 to 30-percent range of variation. Caraher and others definition of a "high-density stand" is not defined in terms of overstory and understory structure that can be translated easily for comparison with our data. Moreover, we did not estimate standard errors for stratified samples for structure classes of the individual overstory dominant species (appendix B) because the procedure was too lengthy for this report.

For a preliminary estimate of variability in high-density stands, we calculated the standard error of our sample mean using random sampling methods instead of stratified sampling methods. Our estimates of variability for ponderosa pine are 0.6 to 2.3-percent for the single canopy SSP class; 0.2 to 1.3-percent for the two-layered young class; and 4.5 to 10.6-percent for the two-layered mature stage. These values are within the historical range defined by Caraher and others (1992) for ponderosa pine. The first two classes are probably most similar to what Caraher considers high-density stands, but further definition of high-density using canopy closure might yield different, but probably not much different, estimates. Current estimates of percentage area exhibited the SSP and young stands were above the range of historical variation, as were Caraher's estimates but the mature class was below the historical range. Lodgepole pine in all size classes was less than 5-percent of historical and current landscape area in the Grande Ronde, which was far smaller than the 20 to 30-percent historical range of variability and current estimates of Caraher and others.

Landscape pattern—Fire exclusion in the Grande Ronde appears to have simplified landscapes as hypothesized. Wilderness watersheds became less diverse and more contiguous, and managed watersheds became more diverse and fragmented. Analysis of change in patterns in all watersheds from all basins revealed clear relations between increased logging and decreased patch sizes and contagion (increased fragmentation), as well as increased patch and edge density. Substantial change in pattern occurred even in the absence of logging. Where logged area was high, the predictability of pattern change was low, that is, much residual variation was present, and variation occurred in both positive and negative directions. These results might be explained in terms of the underlying environmental gradients, other disturbances, or sampling methods.

Pattern is partially determined by environmental gradients, which constrain the effects of disturbance in altering pattern (Turner 1989). Environmental gradients influence the basic landscape pattern by way of the interactions of landform, soils, and climate. As environmental gradients change across a river basin, the underlying vegetation pattern also changes. If patch sizes of logged areas match the patch size determined by background gradients, then little change in the whole pattern will be recorded in terms of patch size and density. This approach was taken in some "new forestry" plans for watershed management and fire recovery, such as the Shasta Costa Timber Sale and Integrated Management Plan (Siskiyou National Forest 1991), and the Silver Fire Recovery Plan (1990) of the Siskiyou National Forest. Logged patches that do not match the "grain" of the landscape will result in fragmentation. Fragmentation or changes in the distribution of vegetation and pattern may be acceptable, however, within limits of variation determined from studies of disturbance regimes in similar landscapes that have natural conditions, however these might be defined. No doubt, much of the residual variation also could be explained by disturbance from insects and diseases (Caraher and others 1992; Gast and others 1991; Hessburg and others 1993).

Some of the effects we observed may also be a result of sample size and distribution. A larger sample of wilderness areas in all the basins would allow better analysis of the effects of timber harvest and other management that follows from a well-developed road system. Different analysis techniques would also allow for a more sophisticated analysis of our sample data. Our stratified random sampling design by subbasins was the best design for assessing basin-wide changes. Further stratification of the data by

wilderness and managed forest or by elevation zones presented an unconventional "post-stratification" statistical analysis that was not resolved for this report. We have 36 additional pairs of sample watersheds already mapped by the original Forest mapping teams, but these data have not been entered for analysis in GIS for lack of time and resources.

Wildlife habitat—Changes in habitat area can be expected to affect species that depend on those habitats. Loss of old-forest and late-seral stands may affect species such as the goshawk and pine marten, that are associated with those habitats (Thomas 1979). Likewise, species associated with early successional stages may decline with increasing successional advancement of landscapes. A detailed assessment of the effects of landscape change on animal communities could now be completed and would require a complex analysis that combines habitat areas determined in this assessment and information on wildlife habitat relations (for example, Raphael 1988, Raphael and others 1988). Detailed wildlife-habitat relations data, including density of species, do not exist for most eastside vertebrate species, but wildlife habitat relations data for the Blue Mountains (Thomas 1979) might be used to make assessments of relative change in the abundance of species or groups of species with changes in habitat area. The implications of change in landscape pattern will necessitate a separate analysis based on life history and population structure of individual species or groups (for example, Hansen and Urban 1992; Lehmkuhl and Ruggiero 1991).

A basic assessment of risk to wildlife associated with changes in vegetation pattern can be made from the empirical and theoretical literature on population viability analysis (Gilpin and Soule 1986) and risk analysis (Jurgensen and others 1993; Marcot 1986). In general, the primary consideration in determining wildlife risk to landscape change is the rarity of the species in terms of relative abundance and geographical distribution. Rare or uncommon species will more likely be susceptible to fragmentation simply from the loss of habitat but also from isolation of subunits of the populations when habitats become fragmented. After rarity, two primary considerations are body size, which influences population density, and mobility, which determines how well the species overcomes isolation of habitat patches. Lehmkuhl and Ruggiero (1991) contended that small species such as amphibians and small mammals are susceptible to fragmentation because they are relatively less mobile than large animals and are more susceptible to isolation in fragmented patches. Their small size allows for relatively large population densities in small patches, however, which allows populations to persist longer in isolation. Large mammals and birds, to the extent they depend on specific habitat, are susceptible from the standpoint that large body size requires large habitat area, but their high mobility allows them to more easily overcome fragmentation of habitat patches. Medium-size birds and mammals, such as pine marten, and forest owls, are most susceptible to fragmentation. Relatively large body size dictates greater resource requirements and smaller population sizes than small species, hence less ability to persist in isolation. Also, intermediate mobility relative to the larger species suggests that habitat fragmentation and isolation will require greater effort and risk to predation in finding adequate resources.

Eastside wildlife are adapted to a landscape made diverse by environmental and disturbance gradients. A critical question to answer before setting goals for wildlife in relation to landscape pattern is whether current eastside conditions are more or less diverse today than 100 years ago before fire suppression began to alter landscape pattern. We are now seeing landscape patterns quite different from those occurring before fire exclusion and other human intrusion. Another point to consider is that timber harvest and insect outbreaks, and disease infestations have partially altered or reversed the homogenizing effect fire suppression has had on landscape patterns during the last 90 years. The question surrounding eastside forest diversity could be better answered by modeling landscape change retrospectively.

Vegetation management considerations—Identification of ecosystem attributes, processes, scale, and range of variation are critical aspects of managing vegetation and ecosystems in general (Diaz and Apostol 1992, Risbrudt 1992). We have identified elements of eastside forested landscapes and patterns of change over the last 35 to 50 years, and estimated the range of variation occurring then. Estimating the range of variation for an earlier period before fire suppression will require reconstructing landscapes, most likely by analysis of age-class distributions.

An important question is: What estimate of variation is most appropriate for management? We used the standard error of the stratified sampling mean but could have used other estimators to define the range of variability. The range of values (minimum and maximum), standard deviation, or confidence intervals with specified probabilities of error (for example, 90 or 95-percent) could alternatively be used to define the range of variability. We believe that the range is too strongly influenced by outliers, or extreme values, to be useful except in a general sense; this belief was borne out by our data, which exhibited that watershed samples varied widely in vegetation attributes. Estimating the standard deviation of an attribute from a stratified random sample such as ours is problematic because the variance of a variable is composed of variation within subbasins and among subbasins. Thus, choosing which estimate of variability was most relevant to managing a particular ecosystem would be essential. Moreover, estimating stratified sampling variation requires techniques more complex than commonly used in standard statistical analysis based on simple random sampling. The standard error, which we have used to estimate ranges of variation, is more simply calculated for stratified samples than is the standard deviation. Because most ecosystem assessment for management will be sample-based, the standard error is perhaps the most appropriate estimate of variation with which to compare current and historical conditions.

Insect and Disease Hazard—Insect and disease hazards have changed in response to several management practices. Fire and insect defoliator suppression and selective harvesting appear to be primary causes of change in vegetation conditions and associated hazards (Agee 1993, Hessburg and others 1993, Oliver and others 1993). Management practices have increased insect or pathogen hazards relative to historical baseline conditions in some watersheds and have decreased them in others. With few exceptions, basin-scale analysis of insect and disease hazards is clearly less useful than analysis of watershed conditions. Future analyses should focus at the watershed scale.

Trends reported here are probably conservative compared with the scale of change in vegetation conditions that may have actually occurred since the turn of the century when active fire suppression began. The oldest available aerial photographs used to interpret historical vegetation conditions in any watershed or basin came from the mid-1930s; most photos were from the 1940s and 1950s. Unfortunately, we were unable to locate older photos that would show change from 1890. Such photos would likely provide evidence that changes in vegetation conditions and associated hazards since 1900 are much greater than we are currently able to show.

Defoliators—As was expected, the watersheds with the greatest defoliator hazard occurred in the Douglas-fir and grand (white) fir series. Increases in hazard were associated with increased host abundance, increased canopy layering and host density, and increased continuity among host stands. Hazard increased in about 20-percent of the sample watersheds but decreased in about 25-percent. Watersheds with decreased hazard had Douglas-fir and grand fir overstories that had been harvested in recent decades, influencing canopy layering, host abundance, and host type continuity. Also, numerous stands had been regenerated, as was particularly apparent in the Grande Ronde basin. We intend to explore in more detail the bases for hazard increases and declines in future analyses.

Hazard data suggested that defoliator hazard stayed roughly constant on about 55-percent of the sample watersheds over the last 40 to 50 years. We suspect this means two things: that a fair amount of defoliator hazard was normal in some landscapes of the Douglas-fir and grand fir series; and that change in vegetation conditions occurred before the period we have examined resulting in high defoliator hazard all during our sample period. We also suspect that examination of vegetation conditions on the eastside of the Cascades before the turn of this century would reveal dramatically different landscape composition and structure. Study of specific landscape-development histories would reveal much of the needed information about former and future landscape development trajectories and associated insect and disease hazard. The clearest picture of sustainable future conditions and their range of variability will most likely come from such studies.

Bark beetles—Douglas-fir beetle hazard increased in about 30-percent of the sample watersheds, indicating measurable increases in size, age, abundance, and density of Douglas-fir. Our field observations of the major Douglas-fir beetle mortality areas of the last 6 years suggest that Douglas-fir in riparian zones have been hardest hit by bark beetles.

Western pine beetle hazard to mature and overmature ponderosa pines decreased to some degree in about 45-percent of the sample watersheds, most likely because of extensive harvesting of ponderosa pine over the last 100 years (Oliver and others 1993). Selective harvest and overstory removal targeted mature and overmature ponderosa pine overstories of mid- and late-seral stands (appendix B). Effective fire suppression has allowed ponderosa pine, Douglas-fir, and grand fir understories to develop under old pine overstories, resulting in greater competition for limited soil moisture and nutrients. Ultimately, old pine overstory trees become stressed and succumb to western pine beetle attack.

Changes in western pine beetle (Type 2) and mountain pine beetle (Type 2) hazards in immature, overstocked ponderosa pine were likely the result of fire exclusion and timber harvest. Bark beetle hazards in young, overstocked ponderosa pine stem from the fire events that created the stands. Regenerated areas after large fires currently have high hazard to western and mountain pine beetles. Ponderosa pine seeded in at high densities after fire, and densities have remained high in some watersheds to the present day. Other watersheds have been thinned, and bark beetle hazards have been reduced. A good example of this is the "Blackbark Project" on the Deschutes National Forest, where over 55,000 ha of overcrowded, young ponderosa pine were thinned under an accelerated program to avoid catastrophic losses to beetles.

Mountain pine beetle, Type 1 hazard, increased substantially in only 10-percent of the watersheds. Likewise, only 10-percent of sample watersheds displayed a substantial reduction in Type 1 hazard. In general, mountain pine beetle outbreaks have been somewhat longer, more extensive, and more frequent in this century than historically (Hessburg and others 1993). As a result, much of the lodgepole pine mortality that might have occurred, has already occurred, especially in the lodgepole dominated watersheds of the Grande Ronde and Deschutes basins. Type 1 mountain pine beetle hazard depends primarily on lodgepole pine size, age, and density. In mixed and pure stands of lodgepole pine, many of the large-diameter trees have already been killed by beetles. In watersheds of the Pend Oreille and Methow basins, where Type 1 hazards were moderate, dense lodgepole pine stands are common, but tree diameters are not yet sufficiently large to support a catastrophic outbreak.

Fir engraver hazards declined in 70-percent of Grande Ronde watersheds, which may be attributed to recent extensive harvest of sawtimber grand fir (Oliver and others 1993). The decline in fir engraver hazard in the Grande Ronde basin has not come without cost. Grand fir stumps are readily infected by spores of annosum root disease (S-group), and we can assume that future S-group annosum root disease incidence will be correspondingly high, unless stumps were treated with borax immediately after harvest (Hessburg and others 1993).

Dwarf mistletoes—Douglas-fir dwarf mistletoe hazard is greatest on poor sites where Douglas-fir is abundant, and canopies are layered. This mistletoe is among the most widespread and damaging of all forest diseases (Hessburg and others 1993). In this hazard analysis, only one watershed received a score that rated as high hazard, four others were at the top end of moderate; all others were low or moderate hazard. Unless Douglas-fir dwarf mistletoe is exceedingly widespread and severe, it can probably be considered at best a watershed-scale hazard. Stands and subbasins are influenced by its widespread occurrence, but rarely is the influence of this disease itself of landscape proportions. As a "ladder" fuel that carries surface fire to crowns, the severity of Douglas-fir dwarf mistletoe may be an important landscape consideration.

Western dwarf mistletoe occurs in only about 25-percent of ponderosa pine stands, and is likewise not a watershed scale hazard (Hessburg and others 1993). Hazards only increased in Grande Ronde and Deschutes watersheds where ponderosa pine understories had developed because of the lack of regular

underburning. All watersheds rated a score of low hazard for this insect, and all changes were within the low hazard rating. Similarly, few changes occurred in either western larch or lodgepole pine dwarf mistletoe hazard. Mountain pine beetle mortality over the years has created multicohort stands, thereby increasing hazard. Reductions in larch dwarf mistletoe hazard in a few watersheds of the Grande Ronde and Pend Oreille basins appear to be associated with harvest removal of larch overstories.

Root diseases—In general, Douglas-fir and grand fir have increased in abundance in most watersheds, and root disease has increased accordingly where it was present in historical infection centers. Management has increased the scale of effects of S-group annosum root disease as a disturbance within the grand fir series. By having the capacity to spread to new sites by spores, grand fir stumps created by harvesting are new future foci of this disease. This effect can be negated, if seral species are grown. If grand fir is to be an important part of these future stands, we can expect substantial increases in mortality from this root disease, which should be considered when developing alternative management strategies.

Clearly, the effects of insects and diseases have increased in some watersheds and decreased in others. Under ecosystem management, insect and pathogen populations and effects should be managed within historical ranges of variability. Pathogen and insect disturbance effects would ordinarily be important enhancements to a wide variety of essential ecological processes; that is currently not the case. Landscape structure and composition should be managed within historical ranges of variability to properly rescale insect and pathogen disturbances. Pathogens and insects are currently responding to the increasing abundance of their hosts. When fire or its effects are restored, landscapes will take on many of the characteristics common to historical landscapes that naturally regulated the extent and effects of insect and pathogen disturbances.

Fire and Smoke

Fuel loading—We assessed the fuel loading for the duff and the dead, woody fuels on the ground but were not able to address tree-crown fuels and live vegetation. Confining the study to dead ground fuels underestimates fuel loading by 5 to 50-percent (Anderson 1982, Snell and Anholt 1981, Snell and Brown 1980). This underestimate provides a lower estimate of fuel consumption and smoke produced than would likely occur.

No significant differences between historical and current fuel loadings at the river basin scale were noted because of the high natural variability within and among watersheds. Several large differences were evident at the watershed scale, however. A decrease in fuel loading from historical to current conditions was often related to a natural disturbance (wildfire) or human activity (logging). An increase in fuel loading was often associated with a more homogenous landscape, fewer vegetation types, and less area in early successional species and young stands. This vegetational shift was probably due to succession advances under the influence of fire suppression and selective timber harvesting.

Fire behavior—Logged area generally exhibited a strong association with increased ROS and FL (table 5), indicating that tree harvesting affects potential fire behavior within landscapes. Wilson and Dell (1971) described two primary reasons for the fuel and potential fire problems in Pacific Northwest forest and rangelands: fire exclusion has allowed unnatural and hazardous fuels to accumulate, and intensive forest management annually produces high loadings of slash fuels. Slash fuels, a by-product of clearcutting, thinning, and other tree-removal activities, create both a short- and long-term fire hazard to ecosystems. The potential rate of spread and intensity of fires associated with recently cut slash is high, especially the first year or two as the material decays (Anderson 1982, Maxwell and Ward 1976). High fire-behavior hazards associated with recently cut slash, however, can extend for many years depending on the tree species (Olson and Fahnestock 1955). Even though these hazards diminish, their influence on fire behavior can linger for 20 to 30 years in the dry forest systems of eastern Washington and Oregon.

Slash disposal by prescribed burning, the most common management approach, comes with an associated high risk of an escaped wildfire. Agee (1989) reported that nearly 30-percent of the area burned by wildfires in western Oregon and Washington since 1910 have resulted from escaped fires associated with broadcast-burning of timber-harvest residues. Comparable data were unavailable for eastside systems, but the hazards are common to both sides of the Cascade crest.

Regeneration and successional development patterns can have a profound effect on potential fire behavior within landscapes by enhancing or diminishing fire spread (Agee and Huff 1987, Saveland 1987). Spatially continuous fuels associated with thick regeneration in plantations can create high surface-fire potential during early successional stages. Most of the roughly 275 ha of plantations, 1 to 25 years old, burned in the 3500 ha, 1991 Warner Creek Fire in the Willamette National Forest (Huff, unpublished data; USDA 1992). The fire moved swiftly through the openings created by historical harvests, killing nearly all of the regeneration.

Certainly, ecosystem dynamics have been severely altered by both fire exclusion and escaped fires associated with logging activities. These management interactions when combined with other managed options, such as grazing, make current landscape patterns somewhat more difficult to interpret. Fire influences before the historical period add another scale of complexity. In the Grande Ronde River Basin, for example, where fire behavior characteristics were poorly correlated with area logged (table 5), a high ROS relative to other river basins was observed, as was a substantial ROS decrease from historical to current conditions (fig. 32). A significant decrease in area of early seral structural stages was also detected (fig. 14), as was a substantial (16-percent) increase in area logged (fig. 19). Sixty percent of the sample watersheds were dominated by a wilderness land-use designation. The large increase observed in logging activity, therefore, was concentrated in just a few sample watersheds. Many fires burned in the Grande Ronde River basin just before the historical period, shifting the landscape dominance to primarily early-seral species (appendix E). Many such fires, either deliberate or accidental, were, no doubt, associated with human activities and with the extensive livestock grazing in this area at the turn of the century (Shinn 1980). These fires were so widespread that, despite a 15-percent increase in logging activity between historical and current conditions, the river basin displayed a significant decline in the area in early-seral stages. Meanwhile, fire suppression activities were most likely successful between historical and current periods, which reduced the abundance of early-seral vegetation in the landscape mosaic (appendix E).

We estimated the ROS and FL primarily of surface fires, and to some extent, understory fires from a landscape perspective, but were unable to predict crown-fire behavior because estimation techniques are still being developed. Confining the study to just surface and understory fires grossly underestimated the potential effects of fire and fire-related processes within ecosystems. Strauss and others (1989) estimated that large fires, primarily crown fires, have accounted for more than 80-percent of the area burned in the western United States. Landscape analyses of change in crown-fire behavior should be possible in the near future.

Crown fires are high-intensity and rapidly moving fires that kill most or all overstory vegetation, and initiate secondary succession. From a landscape perspective, however, not all trees die in a crown fire. The richness and diversity of landscape patterns are often tied to random behavior patterns of historical crown fires. The interplay between burned and unburned patches gives landscapes compositional and structural variability. These types of patterns were well illustrated by the 1988 Yellowstone fires (Romme and Despain 1989). In eastern Washington and Oregon, vegetation series such as lodgepole pine or subalpine fir, which are included in a high severity fire regime, typically experience crown fires as part of the natural succession cycle (Agee 1993). Subsequent analyses will need to address the importance of crown fires in these high-severity regimes to maintain ecological processes, characteristics, and health—with and without prescribed fires that may or may not approximate the effects of crown fires.

Repeat photographs of the northern Rocky Mountains collected and taken by Gruell (1978) graphically illustrate how landscape composition and structure can change, in the absence of major disturbances such as fire, over 60 to 80 years. Ecological change caused by fire exclusion, however, can be difficult to measure and interpret using aerial photographs. The time elapsed between historical and current aerial photographs varied among the river basins from about 35 to 50 years (table 1), which is a relatively short period to detect change associated with fire exclusion yet changes were detected. Important changes in vegetation composition and landscape patterns in moderate to long fire-return intervals associated with fire exclusion may not be recognized in that short interval (Agee 1993). Conversely, within a few decades and within low-severity, frequent-fire regimes, change from fire exclusion in understory composition and structure can be substantial. Yet, these understory characteristics are difficult to see and interpret accurately from aerial photographs. Even so, fire exclusion is likely linked to some of the major shifts in understory plant cover and composition observed among river basins. For example, understory tree cover—especially shade-tolerant species—and shrub cover generally increased uniformly among the river basins, and grass cover tended to decrease (fig. 13). Likewise, clump size within polygons shifted from small clumps historically to large clumps currently (fig. 17). This shift would indicate that gaps between tree clumps closed because fires were excluded.

The severity of ecosystem stress from fire exclusion is complex and poorly understood. Interactions of biotic and abiotic factors with fire tend to be circular (Kauffman 1990). Biotic communities, although adapted to specific fire regimes, influence the pattern and occurrence of fire. Therefore, long-term changes in vegetation composition and structure, and in the dead fuel complex—often associated with fire exclusion—will likely change the fire regime. Consequently, ecosystem responses to fire are less predictable, especially if species are poorly adapted to such shifts.

Smoke production—Areas where fire had been excluded exhibited a trend toward increased fuel loadings and increased smoke production from wildfires. For example, if a wildfire occurred today in watershed 55 in the Grande Ronde River Basin, 258 kg/ha more smoke would occur than if the same wildfire had occurred in the past (figs. 53, 54). This watershed is in a wilderness area where no management activity, except wildfire suppression, has occurred. Wildfire suppression increases fuel loading and results in an increase in potential smoke production.

Watershed 35 in the Grande Ronde and watershed 30 in the Yakima River basin exhibited an opposite trend. Watershed 35 decreased in wildfire smoke production 98 kg/ha, and watershed 30 decreased 159 kg/ha from historical to current conditions (figs. 53, 55, 56). Our further investigation indicated that both watersheds have burned during several wildfire episodes, although wildfire suppression management strategies were in place. This accounts for vegetation shifts, less fuel on the ground, and less smoke production.

We also noted a large difference between wildfire and prescribed-fire smoke production. First, wildfires generally occur during droughts; consequently, a lower fuel moisture content was used to represent wildfires, which increased the amount of fuel consumption compared to prescribed fires. Second, the emission factor for wildfires is about one-third higher than that of prescribed fires (Hardy and others 1992).

To understand the magnitude of the differences between prescribed fires and wildfires, assume 20,000 ha burned during a wildfire in the Grande Ronde River basin now. Multiplying the area burned by the current emission production figure estimated for the basin (712 kg/ha of PM₁₀ for wildfires) shows that over 14 million kg of PM₁₀ would be released into the atmosphere from the fire. If the same area is prescription burned, 372 kg/ha of smoke would be produced, resulting in a total release into the atmosphere of more than 7 million kg of PM₁₀, nearly half the projected emissions for a wildfire in the same area.

If prescribed fire becomes a major tool for managing ecosystems, we can also use the PM₁₀ smoke-production figures to project future smoke production. For example, Grande Ronde sample watershed 4 is 6196 ha. The average area prescription burned within that watershed was 225 ha/year during 1990 and 1991. Let us assume the entire watershed will need to be treated with fire periodically during the next 15 years—assuming the forested areas that have 80 years of fuel build-up, and dead and dying trees, are brought to lower hazard level. This treatment would result in a managed fire target of 413 ha/year.

If we multiply the current prescribed-fire production of emissions at the Grande Ronde River basin (fig. 46) by the projected area to be burned per year in the future for watershed 4 (413 ha), and compare that result with the current burning program (225 ha), the difference is substantial: from 83,700 kg to 153,636 kg. A portion of the PM₁₀ could be reduced by burning when less fuel is consumed, as well as by mechanically treating fuels so that burning is not needed and by conducting burns when dispersion conditions and wind direction are favorable. If, in Grande Ronde watershed 4, a wildfire burned 413 ha/year, 294,056 kg of PM₁₀ would be produced—nearly double the amount that would result from prescribed burning (fig. 52).

Fire management considerations—Fire is one of the most paradoxical ecosystem processes confronting resource managers: fire can be natural or unnatural depending on the type of ignition; can be prevented and suppressed or allowed to run its course depending on the land management goals; can be an ally in reducing unwanted logging slash or an adversary as an ecosystem-damaging wildfire, depending on the situation and people's preferences; and can either be a tool to restore and maintain desired ecosystem characteristics or a public health hazard, depending on which way the wind blows. Because fire's identity is so conflicting, it remains a resource management enigma.

Because fire has been labeled as a “destructive process” for so long, the beneficial aspects of fire in sustaining ecosystem health have largely been ignored in developing and implementing fire management strategies. These strategies have focused more on prevention and control of fire than on using it as a management tool to achieve multiple-use objectives. Where fire has been used, the purpose has been narrowly focused to reduce risks associated with slash fuels (Agee 1990). Yet, after nearly a century of wildfire control and prevention, the threat of large damaging wildfires has increased in many ecosystems throughout the Pacific Northwest (Deeming 1990). Little disagreement exists among scientists and public and private resource managers—all acknowledge that an unnatural and hazardous buildup of dead and live fuels has accumulated in eastern Washington and Oregon over many decades. Clearly, the long-term health and vitality of these ecosystems will be crucially linked to future fire management strategies.

With widespread shifts towards fire behavior that is more difficult to control, the task of restoring these systems seems daunting. Initial efforts should focus on ecosystems that are at greatest risk—those with an historical low-severity, frequent-fire regime. For these systems, change associated with decades of fire suppression can be substantial (Gruell and others 1982). Ecological restoration will undoubtedly be expensive and may take decades.

Restoring structure and processes that approximate the natural fire regime should be among the primary goals for maintaining healthy ecosystems in eastern Washington and Oregon (Agee and Huff 1986). Restoration objectives using prescribed fire include regulating stand composition, reducing plant competition, and modifying fuels (Martin 1990). Although fire can be used to achieve these objectives, its use should be delayed if extensive ladder fuels or other dangerous fuel conditions exist. Dangerous fuels should be removed mechanically first. Once the desired structure is restored to approximate the natural state, prescribed fires or natural fires can be used to maintain desired conditions and processes (Agee and Huff 1986).

If people can accept that earlier fire-dependent landscapes were more stable, and can agree that they are more desirable, then prescribed fire, combined with mechanical treatments or other management alternatives, will be necessary to restore or maintain fire-adapted ecosystems. Prescribed fire has the potential to temporarily degrade ambient air, impair visibility, and expose people to concentrations of smoke. These negative effects of prescribed fire contradict current State and national air-quality regulations. Scientists will need to describe and quantify—and the public will need to understand—the tradeoffs among increased prescribed fires, wildfires, ecosystem health, visibility degradation, and public exposure to smoke.

One of the most important tradeoffs to consider is the substantial increase in smoke production from wildfires over prescribed fires. Wildfires occur when fuels are dry and fuel consumption is greater; wildfire fuels are consumed during a less-efficient smoldering stage, which nets about twice as much PM₁₀ as a prescribed fire. Prescribed fire can be used to restore or maintain fire-adapted ecosystems, reduce the potential of wildfire, and considerably reduce PM₁₀ production, relative to wildfire. In addition, prescribed fires are planned in advance, and four mitigation techniques can be used to further reduce effects on air quality. Managed ignitions can be planned for periods when smoke will disperse quickly, smoke will more often avoid sensitive airsheds, less fuel will be consumed or consumption will be more efficient and produce less smoke, and fuels have been removed or reduced. Where specific objectives are to be met, some of these mitigation techniques may not be fully used.

Wildfires are not planned, so use of mitigation techniques is impossible, and fires are usually quickly suppressed. Smoke generated by wildfires is directed and concentrated according to the prevailing wind and atmospheric stability. Wildfires often occur during summer when fuel moisture is low, fuel consumption and smoke production are high, and stable atmospheric conditions may persist. Wildfire does have one advantage over prescribed fire: it might not occur. Will people be willing to accept smoke from prescribed fires spread out over a period of years, or is it preferable to gamble that a catastrophic wildfire, which sends out large amounts and great concentrations of smoke in a few months, will not occur?

The public has previously chosen to bear the costs associated with clean air. Will the public value air quality more than forest ecosystem health and choose to accept wildfire in place of managed fire? Probably yes, unless a strategic plan is developed to address all regulatory requirements and health risks associated with prescribed fire; the public understands the tradeoffs associated with clean air; public regulatory agencies participate in fire management planning; and a strong research program is provided.

Air-quality considerations are one of the largest barriers to reintroducing fire as a restorative process in eastern Oregon and Washington ecosystems. Regulatory agencies have little or no motivation to permit a significant increase in smoke emissions unless managers can demonstrate that burning can be accomplished without violating air-quality standards or putting public health at risk. Managers must also work with regulatory agencies to weigh the potential for effects on human health from unmanageable wildfire smoke against increased emissions from managed burning (Craig 1990). Trading reduced slash burning for increased prescribed fires in ecosystem restoration projects would allow some increased usage of managed fire, but this limited increase would still result in increased risk of wildfires. Greater management action is required to restore fire regimes to historical conditions and hazards. Harvesting practices that minimize the need to treat slash fuels with fire should be investigated. Economic assessments of such practices will need to address the benefits of restoring ecological health.

Increased funding should also be considered. Funding for fire management activities should be increased to accomplish ecosystem-based management strategies. Funds currently used for fire prevention and control could be increased to include restorative activities. Restoring and maintaining fire-related processes through prescribed fire and prescribed natural fire benefits a diverse array of ecosystem properties (Little 1990). Wildlife, insect and disease, timber, wilderness, recreation, and other groups charged with multiple-use management of resources on public lands, need to recognize the importance of fires to long-term

ecosystem health and the availability of their respective resources. Fire management budgets alone cannot solve this extensive problem. Increased funding is necessary to achieve optimum vegetation structure, composition, and processes across a variety of landscape scales, resource groups could draw upon these funds to collectively achieve ecosystem-based goals, including maintaining fire-related processes.

Action should be taken immediately to bring eastern Washington and Oregon ecosystems back into balance by approximating the historical role of fire. The longer landscape-scale reintroduction of fire is delayed, the higher the costs and risks become. Fire is an essential component in the dynamics and sustainability of many ecosystems in eastern Oregon and Washington. Fire is not a tool for all sites, but prescribed fire should be available for sites and landscapes where its use is appropriate. Proper application of fire can be the best option for meeting specific objectives while creating the fewest adverse effects.

Additional Research Needs and Opportunities

To develop management strategies for ecosystems that approximate natural processes, managers will need to be knowledgeable of the ecological effects of natural disturbances such as fire, insects, and diseases. Plan development and implementation to sustain ecosystem processes and to approximate their effects will require intensive ecological characterization of planning areas.

This report is a first attempt at such an ecological assessment and it describes basic variability in forest composition, structure, patterns of change, and associated hazards. Many research and management questions are still to be answered. Further analysis of these data, and collection of supporting data will, no doubt, reveal new information useful in ecosystem management.

With a small investment, the current data base could be both doubled and vastly improved—simply by digitizing into GIS the second-priority watersheds, which were mapped by Forest Service teams for this assessment, but not yet digitized. The structure and methods for completing more comprehensive analyses have been formulated through this initial analysis of the data base; further work could begin immediately and move ahead quickly. We propose the following additional research than can be accomplished by building onto the base already established.

Additional research related to vegetation—

- ☐ Validate qualitative, large-scale, and less-costly ecosystem assessments, such as Caraher and others (1992) approach used for the Blue Mountains; or use the data for a double-sampling approach to other such large-scale assessments.
- ☐ Examine in detail the variation in ecosystem properties by vegetation series and management history, such as, wilderness vs. managed forest.
- ☐ Examine pathways of vegetation change through more detailed analyses of vegetation composition and structure, and through estimation of transition frequencies from historical to current times to better model landscape change.
- ☐ Determine how the scale of vegetation pattern within watersheds has changed—that is, the scale of similarity from historical to current times.
- ☐ Identify ecological landscape units in conjunction with existing plant association data collected extensively throughout the eastside region by National Forest ecologists.

- ☐ Use data to assess different alternative landscape management configurations, or desired future conditions, for ecosystem management.
- ☐ Examine how changes in landscape pattern have affected the potential spread of disturbances, such as insects, diseases, and fire, across the landscape.
- ☐ Analyze the effect of landscape change on wildlife habitat and species diversity.

Additional research related to fire behavior and management—

- ☐ Describe the historical range of conditions for fire size, frequency, shape, intensity, and landscape patterns.
- ☐ Describe the historical range of stand structure and composition associated with different fire regimes.
- ☐ Identify species and communities linked to different fire regimes and the nature of those links.
- ☐ Establish sites to scientifically test and monitor prescribed fire methods to achieve desired ecological objectives.
- ☐ Determine where and what types of restoration activities are needed in wildernesses to mitigate the effects of historical suppression activities.
- ☐ Develop fire behavior models for landscapes to simulate future ecological effects from fire.
- ☐ Develop ways to approximate the ecological effects of high-intensity crown fires by using a combination of fire, tree harvesting, and other management techniques.
- ☐ Use intensive field sampling of sample watersheds to examine how fire and management history have influenced vegetation patterns, to develop models for predicting landscape characteristics in areas not sampled as rigorously as in our assessment.

Additional research related to smoke production—

- ☐ Identify citizens, politicians, land managers, and regulators interested in smoke management and assess their informational needs.
- ☐ Photo interpret additional aerial photos to improve the historical baseline for fuel loading, area burned, and emissions produced.
- ☐ Estimate emissions and air-quality effects from a mix of future prescribed fire and wildfire scenarios.
- ☐ Design and implement an information system to enable society and policy makers to make informed choices about the appropriate role of prescribed fire in restoring or maintaining fire-adapted ecosystems.

SUMMARY

We analyzed historical and current vegetation composition and structure in 49 sample watersheds, primarily on National Forests, within the Deschutes and Grande Ronde river basins in eastern Oregon, and in the Methow, Wenatchee, and Yakima river basins in eastern Washington. Historical vegetation patterns were mapped from aerial photographs taken primarily from 1932 to 1945; current vegetation patterns were mapped from aerial photographs taken from 1985 to 1992. We described vegetation attributes, landscape patterns, the range of historical variability, and scales of change.

Forest cover has increased in the Deschutes, Grande Ronde, and Pend Oreille river basins by 8-percent from historical cover, but it remains relatively unchanged in the other three river basins. Forests have become more dense in vertical and horizontal canopy structure. Open bare-ground and grass-forb understories have declined, as understory cover increased with regeneration of shade-tolerant understory species. Horizontal stand density increased in some areas, as shown by increasing size and density of tree clumps within stands. The distribution of forest age classes and structure changed as a result of decreases in early-seral and old-forest structural stages and increases in multiple-canopy, young and mature stands.

The percentage of visible dead trees increased in all river basins. High concentrations of dead trees (10 to 70-percent dead) were mostly found in the Deschutes and Grande Ronde basins, but the affected areas were less than 20-percent of the basin areas. In the Wenatchee and Yakima basins, however, dead trees were less concentrated, accounting for a smaller percentage of the trees in a stand (< 10-percent dead), but this condition was more widespread, occurring in 40 to 50-percent of the basin areas.

Landscape pattern has become more diverse and fragmented over time in five of the six river basins. Current patch sizes are smaller, and edge and patch densities are greater than 50 years ago. Diversity either changed little over time, or changed inconsistently among watersheds. Change in landscape pattern in the Grande Ronde was entirely different, and more closely followed the pattern of change expected with fire suppression. Pattern in wilderness watersheds became more homogeneous rather than fragmented. Diversity decreased primarily because of the 325-percent increase in the area of mid-seral stands. Other landscape pattern attributes varied widely among Grande Ronde watersheds.

Insect and disease hazards changed little at the river basin scale because of considerable variation at the watershed scale. Basin-wide changes were usually less than 10-percent different than historical levels. Moreover, changes in hazard among basins were often inconsistent in the direction, except perhaps for western dwarf mistletoe hazard, which increased in the Grande Ronde (29-percent) and Pend Oreille (11-percent) basins. Large changes in insect and disease hazards were common in individual watersheds, however, which indicated watersheds were the appropriate scale for many insect and disease hazard analyses.

No statistically significant differences in fire behavior between current and historical conditions were detected in any of the six river basins at the basin-scale. Potential rate of spread of fire and flame length were highly variable among sample watersheds in any given river basin. Rate of spread and flame length increases from historical to current conditions were detected in 50-percent or more of the sample watersheds in all but the Grande Ronde and Wenatchee River basins, respectively. In more than half the sample watersheds in the Grande Ronde and Deschutes River basins, potential rate of spread under current conditions was above the threshold where initial control would be difficult. In general, rate of spread and flame length were positively correlated with the proportion of area logged in the sample watersheds. Residues from timber harvesting and vegetation characteristics of plantations appeared to be associated with increased potential surface-fire severity. Large-scale restoration and maintenance of fire-related processes, through prescribed and prescribed natural fires, are urgently needed to maintain ecosystem health throughout eastern Washington and Oregon. Air-quality considerations and budget constraints are major obstacles to ecosystem restoration through prescribed fire.

Changes in fuel loading, fuel consumption, and emission production were often less evident at the river basin scale than at the watershed scale. Wildfires generally produced twice as much smoke as prescribed fires because they occur during drought periods when more fuel is consumed, and because the emission factor is one-third higher than that of prescribed fire. For areas where wildfires occurred or management activity removed fuels between the historical and current periods, a decrease in fuel loading and a subsequent decrease in emission production was often found. In areas where wildfire did not occur and management activities were not evident, a vegetation shift to high-density mixed conifer stands, with an increase in fuel loading and emission production, was often noted. Wildfires provide little opportunity to use emission-reduction techniques.

If people agree that earlier, fire-dependent landscapes are more stable and desirable, then prescribed fire will be necessary to restore or maintain these fire-adapted ecosystems. Prescribed fire can temporarily degrade ambient air quality, impair visibility, and expose people to concentrations of smoke. Scientists will need to describe, and the public will need to understand, the tradeoffs among increased prescribed fires, wildfires, ecosystem health, visibility degradation, and exposure to smoke.

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Conversion factors

Multiply <i>METRIC</i>	by	to obtain <i>ENGLISH</i>
cm	0.3937	inches
hectares	2.471	acres
meters	3.281	feet
meters	0.0497	chains
kilometers	0.6214	miles
grams	0.03527	ounces
kilograms	2.205	pounds
megagrams/hectare	0.4458	tons/acre
grams/kilogram	2.0004	pounds/ton
kilograms/hectare	0.8922	pounds/acre

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APPENDIX A: ASSESSING LANDSCAPE SUSCEPTIBILITY TO INSECTS AND DISEASES: A SUMMARY OF HAZARD VARIABLES AND ANALYSIS METHODS

INTRODUCTION

In this section, we summarize hazard analyses used in the terrestrial landscape assessment to evaluate historical and current susceptibility of vegetation to insects and diseases, in selected river basins. Sample watersheds from the Deschutes, Grande Ronde, Yakima, Wenatchee, Methow, and Pend Oreille river basins were evaluated. Aerial photo interpretation yielded maps of both historical and current vegetation composition and structure for each sample watershed.

Insects

Defoliators—The principal lepidopteran defoliators of eastern Oregon and Washington coniferous forests are the western spruce budworm¹ and the Douglas-fir tussock moth. Eastside forests are primarily comprised of areas of low-to-moderate budworm outbreak frequency (Kemp 1985a, 1985b), although small areas of high outbreak frequency are interspersed throughout. Areas of high outbreak frequency are characterized by low annual precipitation, droughty growing seasons, cold winters, and cool spring and fall temperature regimes. Low outbreak-frequency areas are characterized by high annual precipitation, mild winters, and warmer spring and fall temperature regimes. The Deschutes and Pend Oreille River basins, and the southern half of the Yakima River basin are in low frequency areas. The Methow, Wenatchee, and Grande Ronde River basins, and the northern half of the Yakima basin are in moderate frequency areas.

Mapping susceptibility to budworm—Western spruce budworm (WSB, see table 1) and Douglas-fir tussock moth (DFTM) hazards were combined, although the hazard variables we used were most appropriate to the budworm. Defoliator hazard was mapped for stand polygons containing one or more host species. Stand polygons that did not contain any host species in the understory or overstory were given the lowest possible score for each of the variables. Defoliator hosts are: Douglas-fir, PSME; grand fir, ABGR; white fir, ABCO; subalpine fir, ABLA2; Pacific silver fir, ABAM; Shasta red fir, ABMA; noble fir, ABPR; Engelmann spruce, PIEN; and western larch, LAOC. Defoliator hazard was scored for each polygon from stand attributes associated with five hazard variables: site quality—overstory and understory species composition; host abundance—host crown cover percent; canopy structure—number of canopy layers; density—total crown cover percent; and continuity of host types—according to host - host transition frequencies.

Ranking site quality: 1 = ABAM, ABPR, ABMA, TSHE, THPL, and TSME sites; 2 = ABLA2, PIEN, LAOC, PICO sites; 3 = PSME, ABGR, ABCO sites. Site quality was determined by using the most shade-tolerant species, which were identified in the classification of understory and overstory species composition.

Ranking host abundance: 1 = Nonhost species or < 30-percent crown cover of host species; 2 = 30-50-percent crown cover of host species; 3 = > 50-percent crown cover of host species. Host abundance was calculated by using total crown cover and overstory crown cover polygon data, and overstory and understory species data. Overstory crown cover was subtracted from total crown cover, to obtain apparent understory crown cover. (Maximum crown cover from photo interpreted data was 100 percent.

¹ Scientific names for all taxa mentioned are given in appendix D.

In reality, some overstory and understory crown covers would sum to a value greater than 100 percent.) Polygon overstories and understories were classified as having one, two, or three species. When an overstory or understory was classified as having more than one species, they were assumed equal in abundance, which is consistent with instructions provided to photo-interpretive teams. Host abundance was obtained by computing the overstory and understory crown cover in all defoliator host species.

Ranking canopy structure: 1 = one layer of a host species; 2 = two layers of host species; 3 = more than two layers of host species. Canopy structure was taken from overstory and understory species and from canopy-layering data.

Ranking density: 1 = <30-percent total crown cover; 2 = 30 to 60-percent total crown cover; 3 = >60-percent total crown cover. Density was taken directly from total crown cover data.

Ranking continuity of host types: 1 = <20-percent of the total cell edges in a watershed as host-host edges; 2 = 20 to 40-percent of the total cell edges in a watershed as host-host edges; 3 = >40-percent of the total cell edges in a watershed as host-host edges. Continuity of host types was estimated for polygons using host - host transition frequencies and rasterized watershed data in GIS.

Carlson and others (1985) also used host age and an index of vigor to rate stand susceptibility to budworm. Given the data sources available to this assessment, we could not compute a comparable measure of relative density from our photo-interpreted data. Our measures of stand density using total crown cover and canopy layering should give some indication of relative differences in stand vigor. In eastern Oregon and Washington, stand age and vigor appear to influence the extent of damage associated with budworm outbreaks, but the relation between stand age, vigor, and susceptibility is less clear. We do not include host age or vigor variables in this hazard rating.

Once values for the first four hazard variables were computed for every stand polygon in a watershed, the four ratings were summed for the individual polygons. This sum was the polygon defoliation hazard rating. Partial watershed hazard ratings were computed as the weighted sum of the polygon ratings for hazard variables 1 to 4. Weighting factors were derived by computing the ratio of individual polygon area to total sample watershed area. Partial watershed hazard ratings were completed by adjusting for continuity of host species.

Continuity of host species was scored for whole watersheds by using length-of-edge analyses. Watershed polygon maps were converted to raster format in GIS, based on the presence of host species in the overstory or understory. The total number of edges between host species (host-host edges) cells was divided by the total number of cell edges in each sample watershed. Low continuity (ranking = 1) was indicated by less than 20-percent of the total cell edges in a watershed as host-host edges. Moderate continuity (ranking = 2) was indicated by 20 to 40-percent of the total cell edges in a watershed as host-host edges. Watersheds with high continuity (ranking = 3) of host types were indicated by more than 40-percent of the total cell edges as host-host edges. This index of host continuity was sensitive to the proportion of watershed areas in host types, as well as to the size and spatial distribution of host species stands. Watershed host continuity scores were added to partial watershed hazard ratings to yield complete watershed defoliator hazard ratings.

Watershed scores of 7 or less had LOW susceptibility to defoliation. Watershed scores of 8 to 10 had MODERATE susceptibility to defoliation. Scores greater than 11 indicated HIGH susceptibility to defoliation.

Bark Beetles—Bark beetle hazards were assessed for the Douglas-fir beetle, western pine beetle, mountain pine beetle, and fir engraver. Spruce beetle hazard was not evaluated. Without recent fire or windthrow, hazard for spruce beetle in Engelmann spruce could not be readily identified and mapped.

Douglas-fir beetle—Douglas-fir beetle outbreaks are primarily associated with large wind, fire, drought, and defoliation events. Areas with abundant dwarf mistletoe and root disease in Douglas-fir also support higher Douglas-fir beetle populations in eastern Oregon and Washington. At least 40-percent of the Douglas-fir in eastern Oregon and Washington are infected with Douglas-fir dwarf mistletoe (Bolsinger 1978). An additional 5 to 10-percent are root diseased (Byler 1988). The Douglas-fir beetle is routinely responsible for the demise of Douglas-fir severely infected with dwarf mistletoe and root disease.

Mapping susceptibility to Douglas-fir beetle—Douglas-fir beetle hazard on the eastside is correlated with the incidence and severity of Douglas-fir dwarf mistletoe, Armillaria root disease, laminated root rot, drought, and defoliation. Douglas-fir beetle hazard was mapped for polygons containing Douglas-fir 9 in. d.b.h. and larger. Stand polygons that did not contain any host species in the understory or overstory, were given the lowest possible score for each of the variables. In this analysis, Douglas-fir beetle hazard was scored for each polygon from stand attributes associated with six hazard variables: site quality—overstory and understory species composition; host abundance—host crown cover percent; canopy structure—number of canopy layers; host age—overstory and understory size class; density—total crown cover percent; and continuity of host types for defoliators—according to the continuity index used for defoliators above.

Ranking site quality: 1 = ABAM, ABPR, ABMA, TSHE, TSME, THPL sites; 2 = ABLA2, PIEN sites; 3 = PSME, ABGR, ABCO sites. Site quality was determined as with the defoliators above.

Ranking host abundance: 1 = other species or <30-percent crown cover in PSME; 2 = 30 to 50-percent crown cover in PSME; 3 = > 50-percent crown cover in PSME. Host abundance was calculated by using total crown cover as well as overstory crown cover polygon data, and overstory and understory species data. Overstory crown cover was subtracted from total crown cover to obtain apparent understory crown cover. Host abundance was obtained by computing the overstory and understory crown cover in PSME greater than 9 in. d.b.h..

Ranking canopy structure: 1 = 1 mixed species layer including PSME; 2 = 1 PSME layer; 3 = 2 or more PSME layers. Canopy structure was computed from overstory and understory species and from canopy-layering data.

Ranking host age: 1 = small sawtimber PSME (9 to 15.9 in. d.b.h.) overstory and understory; 2 = medium or large sawtimber PSME (16 to 25 in. d.b.h.) overstory and understory; 3 = mature or overmature sawtimber PSME (> 25 in. d.b.h.) overstory and understory. Host age was approximated from overstory and understory size-class data.

Ranking density: 1 = <50-percent total crown cover; 2 = 50 to 80-percent total crown cover; 3 = >80-percent total crown cover. Density was taken directly from total crown cover data.

Ranking continuity of host types for defoliators: 1 = <20-percent of the total cell edges in a watershed as host-host edges; 2 = 20 to 40-percent of the total cell edges in a watershed as host-host edges; 3 = >40-percent of the total cell edges in a watershed as host-host edges. Continuity of host types was estimated for polygons using length of edge analyses and rasterized watershed data in GIS.

Once values for the six hazard variables were computed for every stand polygon in a watershed, the ratings were summed for the individual polygons. This sum was the stand polygon Douglas-fir beetle hazard rating. Watershed hazard ratings were computed as the weighted sum of the polygons. Polygon weighting factors were derived by computing the ratio of individual polygon acres to total sample watershed acres.

Watershed scores of 6 to 9 had LOW susceptibility to Douglas-fir beetle. Watershed scores of 10 to 13 had MODERATE susceptibility. Scores 14 indicated HIGH susceptibility.

Western pine beetle—Western pine beetle affects ponderosa pine (PIPO) in eastern Oregon and Washington. Large overmature ponderosa pine are susceptible as are immature, overstocked pole- and sawtimber-sized pine. The western pine beetle is often responsible for killing ponderosa pine severely infected by mistletoe, by P-group annosum root disease, by Armillaria root disease, as well as trees severely stressed by persistent drought.

Mapping susceptibility to western pine beetle—Western pine beetle hazards are correlated with stand age, tree vigor, stand density, the incidence and severity of western dwarf mistletoe, Armillaria root disease, P-group annosum root disease, and drought susceptibility. Western pine beetle hazard was mapped for polygons containing ponderosa pine 9 in. d.b.h. and larger. Stand polygons that did not contain any host species in the understory or overstory, were given the lowest possible score for each of the variables. In this analysis, two types of Western pine beetle hazard were scored for each polygon from stand attributes associated with four or five hazard variables: site quality—overstory and understory species; host abundance—host crown cover percent; host age—overstory size class; density—total crown cover percent; and density—degree of crown differentiation.

Type 1 western pine beetle hazard - Damage to mature and overmature PIPO—

Ranking site quality: 1 = ABGR, ABCO, PICO; 2 = PSME; 3 = PIPO, also PSME-PIPO. Site quality was determined by using the most shade-tolerant species identified in the classification of understory and overstory species.

Ranking host abundance: 1 = other species or <30-percent crown cover in PIPO; 2 = 30 to 50-percent crown cover in PIPO; 3 = >50-percent crown cover in PIPO. Host abundance was obtained by computing the overstory and understory crown cover in PIPO.

Ranking host age: 1 = small sawtimber PIPO (9 to 15.9 in. d.b.h.) overstory and understory; 2 = medium or large sawtimber PIPO (16 to 25 in. d.b.h.) overstory and understory; 3 = mature or overmature sawtimber PIPO (>25 in. d.b.h.) overstory and understory. Host age was approximated from overstory size-class data.

Ranking density: 1 = <50-percent total crown cover; 2 = 50 to 80-percent total crown cover; 3 = >80-percent total crown cover. Density was taken directly from total crown cover data.

Once values for the four hazard variables were computed for every stand polygon in a watershed, the ratings were summed for the individual polygons. This sum was the stand polygon Type 1 western pine beetle hazard rating. Watershed hazard ratings were computed as the weighted sum of the polygons. Polygon weighting factors were derived by computing the ratio of individual polygon acres to total sample watershed acres.

Watershed scores of 4 to 6 had LOW susceptibility to western pine beetle. Watershed scores of 7 to 9 had MODERATE susceptibility. Scores of 10 to 12 indicated HIGH susceptibility.

Type 2 WPB Hazard - Damage to immature, overstocked PIPO 16 in. d.b.h. and smaller—

Ranking site quality: 1 = ABGR, ABCO; 2 = PSME; 3 = PIPO, also PSME-PIPO.

Ranking host abundance: 1 = other species or <30-percent crown cover in PIPO; 2 = 30-50-percent crown cover in PIPO; 3 = >50-percent crown cover in PIPO.

Ranking host age: 1 = seedling and sapling PIPO (<5 in. d.b.h.); 2 = poletimber PIPO (5 to 8.9 in. d.b.h.); 3 = small sawtimber PIPO (9 to 15.9 in. d.b.h.).

Ranking density by degree of crown differentiation: 1 = highly differentiated (>100-percent difference in crown diameters); 2 = moderately differentiated (30 to 100-percent difference in crown diameters); 3 = poorly differentiated (<30-percent difference in crown diameters).

Ranking density by total crown cover: 1 = <50-percent total crown cover; 2 = 50 to 80-percent total crown cover; 3 = >80-percent total crown cover.

Site quality, host abundance, and host age were approximated from data as before. Density was taken directly from total crown cover and crown differentiation data. The cumulative Type 2 western pine beetle hazard rating for the watershed was calculated as for the Type 1 hazard.

Watershed scores of 5 to 7 had LOW susceptibility to western pine beetle. Watershed scores of 8 to 10 had MODERATE susceptibility. Scores of 11 to 15 indicated HIGH susceptibility.

Mountain pine beetle—Mountain pine beetles primarily attack ponderosa pine, lodgepole pine - PICO, and western white pine in eastern Oregon and Washington. Western white pine 14 inches d.b.h. and larger, having more than 140 sq. ft. of associated basal area, and older than 140 years are routinely mass-attacked and killed by the mountain pine beetle. Mountain pine beetle hazard for western white pine was not addressed in this hazard assessment because methods of stratifying hazard variables in acceptable detail were unavailable. Poletimber and small sawtimber-sized ponderosa pine and overstocked lodgepole pine are also susceptible. The mountain pine beetle also kills mature and overmature lodgepole pine and trees severely stressed by persistent drought.

Mapping susceptibility to mountain pine beetle—Mountain pine beetle hazards in lodgepole pine (PICO) and ponderosa pine are highly correlated with stand age, overstory size class, and density. Mountain pine beetle hazard was mapped for stand polygons containing host species. Mountain pine beetles hosts in this analysis are lodgepole pine and ponderosa pine. Stand polygons that did not contain any host species in the understory or overstory, were given the lowest possible score for each of the variables. In this analysis, two types of mountain pine beetle hazard were scored for each polygon from stand attributes associated with five hazard variables: site quality—overstory and understory species; host abundance - host crown cover percent; host size—overstory size class; density—total crown cover percent; and density—degree of crown differentiation.

Type 1 MPB Hazard - Damage to overstocked PICO only—

Ranking site quality: 1 = ABLA2, PIEN, TSME; 2 = ABGR, ABCO; 3 = PICO, PSME.

Ranking host size: 1 = seedling and sapling PICO (<5 in. d.b.h.); 2 = poletimber PICO (5 to 8.9 in. d.b.h.); 3 = small sawtimber PICO (9 to 15.9 in. d.b.h.).

Ranking host abundance: 1 = other species or <30-percent crown cover in PICO; 2 = 30 to 50-percent crown cover in PICO; 3 = >50-percent crown cover in PICO.

Ranking density by degree of crown differentiation: 1 = highly differentiated (> 100-percent difference in crown diameters); 2 = moderately differentiated (30 to 100-percent difference in crown diameters); 3 = poorly differentiated (< 30-percent difference in crown diameters).

Ranking density by total crown cover: 1 = <50-percent total crown cover; 2 = 50 to 80-percent total crown cover; 3 = >80-percent total crown cover.

Site quality, host abundance, and host age were approximated from data, as before. Density was taken directly from total crown cover and crown differentiation data. The cumulative Type 1 mountain pine beetle hazard rating for the watershed was calculated as for the Type 1 western pine beetle hazard above.

Watershed scores of 5 to 7 were LOW susceptibility to mountain pine beetle. Watershed scores of 8 to 10 had MODERATE susceptibility. Scores of 11 to 15 indicated HIGH susceptibility.

Type 2 MPB hazard - Damage to immature, overstocked PIPO only—Analysis is identical to that used for Type 2 western pine beetle hazard above.

Fir engraver—All true firs are host to the fir engraver. Fir engraver beetles are often described as secondary bark beetles: beetles lacking a means of overcoming robust trees, that instead attack and overcome trees stressed by drought or pathogens. Grand fir and white fir are primarily affected by fir engraver because they are sensitive to extended drought, and extremely susceptible to three major root diseases: laminated root rot, S-type annosum root disease, and Armillaria root disease. During drought-free periods, fir engraver mortality is an excellent indicator of root disease distribution and severity within the grand and white fir zones.

Mapping susceptibility to fir engraver—Fir engraver stand hazard is correlated with the incidence and severity of Armillaria root disease, laminated root rot, S-type annosum root disease, stand drought susceptibility, and defoliation severity. Fir engraver hazard was mapped for stand polygons containing one or more host species. Fir engraver hosts in this analysis are ABGR, ABCO, ABLA, ABAM, ABPR, and ABMA. Stand polygons that did not contain any host species in the understory or overstory were given the lowest possible score for each of the variables. In this analysis, fir engraver hazard was scored for each stand polygon from stand attributes associated with six hazard variables: site quality—overstory and understory species composition; host abundance—host crown cover percent; canopy structure—number of canopy layers; host age—overstory size class; density—total crown cover percent; and continuity of host types for defoliators—according to the continuity index used for defoliators above.

Ranking site quality: 1 = ABAM, ABPR, ABMA, TSHE, TSME, THPL sites; 2 = ABLA2, PIEN sites; 3 = ABGR, ABCO sites.

Ranking host abundance: 1 = nonhost species or <30-percent crown cover in fir engraver host species; 2 = 30-50-percent crown cover in fir engraver host species; 3 = >50-percent crown cover in fir engraver host species.

Ranking canopy structure: 1 = 1 layer of a fir engraver host species; 2 = 2 layers of fir engraver host species; 3 = >2 layers of fir engraver host species.

Ranking host age: 1 = seedlings, saplings, and poles (< 9 in. d.b.h.); 2 = small sawtimber (9 to 15.9 in. d.b.h.); 3 = medium and large sawtimber (16 to 24 in. d.b.h.) and larger.

Ranking density by total crown cover: 1 = <50-percent total crown cover; 2 = 50 to 80-percent total crown cover; 3 = >80-percent total crown cover.

Ranking continuity of host types for defoliators: 1 = <20-percent of the total cell edges in a watershed as host-host edges; 2 = 20 to 40-percent of the total cell edges in a watershed as host-host edges; 3 = >40-percent of the total cell edges in a watershed as host-host edges.

All stand polygons in a sample watershed were hazard rated according to site quality, host abundance, canopy structure, host age, density, and continuity of host types for defoliators as above. Once values for the six hazard variables were computed for every polygon in a watershed, ratings were summed for the individual polygons. This sum was the polygon fir engraver hazard rating. Watershed hazard ratings were computed as the weighted sums of the polygons.

Watershed scores of 6 to 9 had LOW susceptibility to fir engraver. Watershed scores of 10 to 12 had MODERATE susceptibility. Scores of 13 indicated HIGH susceptibility.

Diseases

Dwarf mistletoes—The four principal dwarf mistletoes of the eastside are specific to Douglas-fir, ponderosa pine, lodgepole pine, and western larch. Ponderosa pine, western larch, and lodgepole pine are the major pioneering conifer species in most of the low- and mid-elevation plant associations of eastern Oregon and Washington. Under natural fire regimes, dwarf mistletoes exert a stabilizing influence on the persistence of early-seral tree species. Frequent fires favor the establishment and perpetuation of seral-tree species, maintaining favorable conditions for the persistence of each host-specific mistletoe. Moderately severe mistletoe infestations favor the torching of the most infested trees, and, with the right fuel and wind conditions, stand replacement crowning fires. By this mechanism, dwarf mistletoes of seral species were historically widely distributed, but at low or moderate severity within their host populations. Dwarf mistletoes of mid- and late-successional species like Douglas-fir, are destabilizing with respect to those specific transitional communities. Crowning fires influenced by mistletoe severity, regenerated seral plant communities rather than mid- and late-successional communities, drastically reducing or eliminating for a period the availability of susceptible host material (Douglas-fir) and an inoculum source of the parasite (Douglas-fir dwarf mistletoe).

Douglas-fir dwarf mistletoe—At least 40-percent of the Douglas-fir in eastern Oregon and Washington are infected with dwarf mistletoe (Bolsinger 1978). Douglas-fir dwarf mistletoe hazard is correlated with the abundance of Douglas-fir, stand structural complexity, site quality, and the presence of other damaging agents that depress tree vigor and render mistletoe-infected Douglas-fir susceptible to mortality by other agents (root diseases, bark beetles, drought, and defoliators). Douglas-fir dwarf mistletoe hazard was mapped for polygons containing Douglas-fir. Stand polygons that did not contain any host species in the understory or overstory, were given the lowest possible score for each of the variables. In this analysis, Douglas-fir dwarf mistletoe hazard was scored for each stand polygon from stand attributes associated with five hazard variables: site quality—overstory and understory species composition; host abundance—host crown cover percent; canopy structure—number of canopy layers; host age—overstory size class; and continuity of host types for defoliators—according to the continuity index used for defoliators above. Actual inventory data on the distribution and extent of dwarf mistletoe is needed for accurate hazard assessment. Lacking these data, only the presence of susceptible hosts in susceptible arrangements can be assessed.

Ranking site quality: 1 = ABLA2, PIEN, ABAM, ABPR, ABMA, TSHE, TSME, THPL sites; 2 = ABGR, ABCO sites; 3 = PSME-PIPO, PSME sites.

Ranking host abundance: 1 = other species or <30-percent crown cover in PSME; 2 = 30 to 50-percent crown cover in PSME; 3 = >50-percent crown cover in PSME.

Ranking canopy structure: 1 = 1 layer of PSME; 2 = 2 layers PSME in mixed species layers; 3 = 2 layers of PSME.

Ranking host age: 1 = small sawtimber PSME (9 to 15.9 in. d.b.h.) overstory or smaller; 2 = medium or large sawtimber PSME (16 to 25 in. d.b.h.) overstory; 3 = mature or overmature sawtimber PSME (> 25 in. d.b.h.) overstory.

Ranking continuity of host types for defoliators: 1 = <20-percent of the total cell edges in a watershed as host-host edges; 2 = 20 to 40-percent of the total cell edges in a watershed as host-host edges; 3 = >40-percent of the total cell edges in a watershed as host-host edges.

All stand polygons in a sample watershed were hazard rated according to site quality, host abundance, canopy structure, host age, and continuity of host types for defoliators as above. Once values for the five hazard variables were computed for every polygon in a watershed, ratings were summed for the individual polygons. This sum was the polygon Douglas-fir dwarf mistletoe hazard rating. Watershed hazard ratings were computed as the weighted sums of the polygons.

Watershed scores of 5 to 7 had LOW susceptibility to Douglas-fir dwarf mistletoe. Watershed scores of 8 to 10 had MODERATE susceptibility. Scores of 11 indicated HIGH susceptibility.

Western dwarf mistletoe—About one-quarter of the ponderosa pine in eastern Oregon and Washington are infected with dwarf mistletoe (Bolsinger 1978). Western dwarf mistletoe hazard is correlated with the abundance of ponderosa pine, stand structural complexity, site quality, and the presence of other damaging agents: root diseases, bark beetles, drought, and defoliators (pine butterfly and Pandora moth). Western dwarf mistletoe hazard was mapped for polygons containing PIPO. Stand polygons that did not contain any host species in the understory or overstory were given the lowest possible score for each of the variables. In this analysis, western dwarf mistletoe hazard was scored for each stand polygon from stand attributes associated with four hazard variables: site quality—overstory and understory species composition; host abundance—host crown cover percent; canopy structure—number of canopy layers; and host age—overstory size class. Actual inventory data on the distribution and extent of dwarf mistletoe is needed for accurate hazard assessment. Lacking these data, only the presence of susceptible hosts in susceptible arrangements can be assessed.

Ranking site quality: 1 = ABLA2, PIEN, ABAM, ABPR, ABMA, TSHE, TSME, THPL sites; 2 = ABGR, ABCO, PICO sites; 3 = PIPO, PSME-PIPO, PSME sites.

Ranking host abundance: 1 = other species or <30-percent crown cover in PIPO; 2 = 30 to 50-percent crown cover in PIPO; 3 = >50-percent crown cover in PIPO.

Ranking canopy structure: 1 = 1 layer of PIPO; 2 = 2 layers PIPO in mixed species layers; 3 = 2 layers of PIPO.

Ranking host age: 1 = small sawtimber PIPO (9 to 15.9 in. d.b.h.) overstory or smaller; 2 = medium or large sawtimber PIPO (16 to 25 in. d.b.h.) overstory; 3 = mature or overmature sawtimber PIPO (> 25 in. d.b.h.) overstory.

All stand polygons in a sample watershed were hazard rated according to site quality, host abundance, canopy structure, and host age as above. Once values for the four hazard variables were computed for every polygon in a watershed, ratings were summed for the individual polygons. This sum was the polygon western dwarf mistletoe hazard rating. Watershed hazard ratings were computed as the weighted sums of the polygons.

Watershed scores of 4 to 7 had LOW susceptibility to western dwarf mistletoe. Watershed scores of 8 to 9 had MODERATE susceptibility. Scores of 10 indicated HIGH susceptibility.

Mapping susceptibility western larch dwarf mistletoe—About one-half of the western larch in eastern Oregon and Washington are infected with dwarf mistletoe (Bolsinger 1978). As with the two preceding mistletoes, western larch dwarf mistletoe hazard is correlated with the abundance of the host—western larch—stand structural complexity, site quality, and the presence of other damaging agents that depress tree vigor and render dwarf mistletoe-infected larch susceptible to mortality by other agents. western larch dwarf mistletoe hazard was mapped for polygons containing LAOC. Stand polygons that did not contain any host species in the understory or overstory, were given the lowest possible score for each of the variables. In this analysis, western larch dwarf mistletoe hazard was scored for each stand polygon from stand attributes associated with four hazard variables: site quality—overstory and understory species composition; host abundance—host crown cover percent; canopy structure—number of canopy layers; and host age—overstory size class. Actual inventory data on the distribution and extent of dwarf mistletoe is needed for accurate hazard assessment. Lacking these data, only the presence of susceptible hosts in susceptible arrangements can be assessed.

Ranking site quality: 1 = ABAM, ABPR, ABMA, TSHE, TSME, THPL sites; 2 = ABGR, ABCO, ABLA2, PIEN, PICO, LAOC sites; 3 = PSME sites.

Ranking host abundance: 1 = other species or <30-percent crown cover in LAOC; 2 = 30 to 50-percent crown cover in LAOC; 3 = >50-percent crown cover in LAOC.

Ranking canopy structure: 1 = 1 layer of LAOC; 2 = 2 layers LAOC in mixed species layers; 3 = 2 layers of LAOC.

Ranking host age: 1 = small sawtimber LAOC (9 to 15.9 in.d.b.h.) overstory or smaller; 2 = medium or large sawtimber LAOC (16 to 25 in. d.b.h.) overstory; 3 = mature or overmature sawtimber LAOC (> 25 in. d.b.h.) overstory.

All stand polygons in a sample watershed were hazard rated according to site quality, host abundance, canopy structure, and host age as above. Once values for the four hazard variables were computed for every polygon in a watershed, ratings were summed for the individual polygons. This sum was the polygon western larch dwarf mistletoe hazard rating. Watershed hazard ratings were computed as the weighted sums of the polygons.

Watershed scores of 4 to 6 had LOW susceptibility to western larch dwarf mistletoe. Watershed scores of 7 to 9 had MODERATE susceptibility. Scores of 10 indicated HIGH susceptibility.

Lodgepole pine dwarf mistletoe—More than 40-percent of the lodgepole pine in eastern Oregon and Washington are infected with dwarf mistletoe (Bolsinger 1978). Lodgepole pine dwarf mistletoe hazard is correlated with the abundance of the host, stand structural complexity, site quality, and the presence of other damaging agents. Lodgepole pine dwarf mistletoe hazard was mapped for polygons containing PICO. Stand polygons that did not contain any host species in the understory or overstory, were given the lowest possible score for each of the variables. In this analysis, lodgepole pine dwarf mistletoe hazard was scored for each stand polygon from stand attributes associated with four hazard variables: site quality—overstory and understory species composition; host abundance—host crown cover percent; canopy structure—number of canopy layers; and host age—overstory size class. Actual inventory data on the distribution and extent of dwarf mistletoe is needed for accurate hazard assessment. Lacking these data, only the presence of susceptible hosts in susceptible arrangements can be assessed.

Ranking site quality: 1 = ABLA2, PIEN, ABAM, ABPR, ABMA, TSHE, TSME, THPL sites; 2 = ABGR, ABCO sites; 3 = PICO, PSME sites.

Ranking host abundance: 1 = other species or <30-percent crown cover in PICO; 2 = 30 to 50-percent crown cover in PICO; 3 = >50-percent crown cover in PICO.

Ranking canopy structure: 1 = 1 layer of PICO; 2 = 2 layers PICO in mixed species layers; 3 = 2 layers of PICO.

Ranking host age: 1 = seedling and sapling PICO (< 5 in. d.b.h.); 2 = poletimber PICO (5 to 8.9 in. d.b.h.); 3 = small sawtimber PICO (9 to 15.9 in. d.b.h.) and larger.

All stand polygons in a sample watershed were hazard rated according to site quality, host abundance, canopy structure, and host age as above. Once values for the four hazard variables were computed for every polygon in a watershed, ratings were summed for the individual polygons. This sum was the polygon lodgepole pine dwarf mistletoe hazard rating. Watershed hazard ratings were computed as the weighted sums of the polygons.

Watershed scores of 4 to 7 had LOW susceptibility to lodgepole pine dwarf mistletoe. Watershed scores of 8 to 9 had MODERATE susceptibility. Scores of 10 indicated HIGH susceptibility.

Root diseases—Susceptibility of stands and landscapes to root diseases was evaluated for laminated root rot, Armillaria root disease, and the S-group annosum root disease. Collectively, they are highly damaging to Douglas-fir, grand fir, and white fir. Throughout the Douglas-fir, grand fir, and white fir zones, root diseases have increased dramatically in distribution and severity in this century, mostly attributable to the marked increase in abundance of susceptible shade-tolerant, fire-sensitive hosts. Root disease mortality annually produces abundant small gaps in forest canopies throughout the east side. This gradual and continuous thinning favors the release and regeneration of additional susceptible shade-tolerant species. Mountain hemlock is also highly susceptible to laminated root rot; other true firs, spruce, and western hemlock are susceptible at maturity to butt defect associated with S-group annosum and laminated root rot.

Hazard for these three root diseases is correlated with site quality, successional stage, stand structural complexity, number of prior logging entries, and the presence of other agents that render root disease hosts susceptible to other mortality factors. Root disease hazard was mapped for polygons containing PSME, ABGR, and ABCO. Stand polygons that did not contain any host species in the understory or overstory were given the lowest possible score for each of the variables. In this analysis, root disease hazard was scored for each stand polygon from stand attributes associated with five hazard variables: site quality—overstory and understory species composition; host abundance—host crown cover percent; canopy structure—number of canopy layers; host age—overstory size class; and continuity of host types for defoliators—according to the continuity index used for defoliators above. Actual inventory data on the distribution and extent of root disease is needed for accurate hazard assessment. Lacking these data, only the presence of susceptible hosts in susceptible arrangements can be assessed.

Ranking site quality: 1 = ABPR, ABMA sites; 2 = ABLA2, PIEN, ABAM, TSHE, THPL, TSME sites; 3 = PSME, ABGR, ABCO sites.

Ranking host abundance: 1 = other species or <30-percent crown cover in PSME and/or ABGR and/or ABCO; 2 = 30 to 50-percent crown cover in PSME and/or ABGR and/or ABCO; 3 = >50-percent crown cover in PSME and/or ABGR and/or ABCO.

Ranking canopy structure: 1 = 1 layer of PSME and/or ABGR and/or ABCO; 2 = 2 layers PSME and/or ABGR and/or ABCO in mixed species layers; 3 = 2 layers of PSME and/or ABGR and/or ABCO.

Ranking host age: 1 = small sawtimber (9 to 15.9 in. d.b.h.) or smaller; 2 = medium or large sawtimber (16 to 25 in. d.b.h.); 3 = mature or overmature sawtimber (> 25 in. d.b.h.).

Ranking continuity of host types for defoliators: 1 = <20-percent of the total cell edges in a watershed as host-host edges; 2 = 20 to 40-percent of the total cell edges in a watershed as host-host edges; 3 = >40-percent of the total cell edges in a watershed as host-host edges.

All stand polygons in a sample watershed were hazard rated according to site quality, host abundance, canopy structure, host age, and continuity of host types for defoliators as above. Once values for the five hazard variables were computed for every polygon in a watershed, ratings were summed for the individual polygons. This sum was the polygon root disease hazard rating. Watershed hazard ratings were computed as the weighted sums of the polygons.

Watershed scores of 5 to 8 had LOW susceptibility to root diseases. Watershed scores of 9 to 11 had MODERATE susceptibility. Scores of 12 to 15 indicated HIGH susceptibility.

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Appendix B: Historical and current percentage area, patch density and patch area of vegetation types on National Forest land in river basins of eastern Oregon and Washington. Historical years for assessment ranged from 1932-59; current years ranged from 1985 to 1990. Area is expressed as the percentage of total basin area.

		Percent area				Patch density (n/km ²)				Mean patch area (ha)		
River basin & overstory cover	Structure ^a	H ^b	C	%D		H	C	%D		H	C	%D
DESCHUTES												
Agric/urban		0.01	0.19	1761%		0.004	0.015	248%		3.0	25.7	757%
Bare ground		19.60	10.49	-46%		0.107	0.258	141%		176.2	57.3	-67%
Water		1.41	1.45	2%		0.057	0.034	-40%		111.2	236.7	113%
Grass/forb		0.80	2.96	268%		0.032	0.217	574%		20.9	14.6	-30%
Shrub		0.31	0.68	118%		0.022	0.041	84%		12.6	14.3	13%
PIPOC ^c												
	SSP	6.27	3.68	-41%		0.085	0.157	86%		36.8	20.2	-45%
	Young	6.93	10.91	57%		0.082	0.231	182%		277.8	46.3	-83%
	Mature	6.96	10.58	52%		0.082	0.265	224%		149.5	84.9	-43%
	Park-like	0.81	0.89	11%		0.022	0.045	105%		54.0	17.2	-68%
	Old forest	2.18	0.79	-64%		0.032	0.018	-42%		66.3	25.3	-62%
PIMO/PILA												
	SSP	0.00	0.01	na ^d		0.000	0.007	na		0.0	7.7	na
	Young	0.28	0.09	-66%		0.021	0.032	51%		40.2	28.5	-29%
	Mature	0.24	0.49	103%		0.036	0.161	352%		21.2	16.3	-23%
	Old forest	0.00	0.01	na		0.000	0.014	na		0.0	11.0	na
LAOC	Young	0.04	0.05	26%		0.004	0.009	139%		12.5	13.0	4%
PICO												
	SSP	4.29	3.57	-17%		0.040	0.135	235%		52.1	46.4	-11%
	Young	6.52	5.78	-11%		0.092	0.227	147%		91.5	48.0	-48%
	Park-like	0.01	0.06	600%		0.019	0.038	100%		5.8	20.3	253%
	Mature	0.02	1.10	5819%		0.002	0.063	3852%		2.4	21.0	778%
PSME/ABGR												
	SSP	0.26	0.52	99%		0.018	0.113	522%		7.2	8.4	17%
	Young	2.15	7.21	235%		0.069	0.234	242%		71.4	37.9	-47%
	Mature	7.95	6.33	-20%		0.087	0.268	208%		118.6	61.0	-49%
	Park-like	0.38	0.09	-75%		0.039	0.008	-80%		21.9	21.6	-1%
	Old forest	2.27	0.22	-90%		0.041	0.010	-75%		90.3	77.0	-15%
ABLA/PIEN												
	SSP	0.12	0.06	-51%		0.004	0.013	256%		92.6	42.7	-54%
	Young	0.44	0.31	-30%		0.024	0.039	58%		42.4	17.8	-58%
	Park-like	0.00	0.08	na		0.000	0.017	na		0.0	26.6	na
	Mature	0.49	0.32	-35%		0.032	0.077	142%		59.0	19.2	-68%
ABAM/TSHE												
	SSP	0.00	0.05	na		0.000	0.029	na		0.0	8.0	na
	Young	0.04	0.17	341%		0.007	0.051	621%		16.5	22.3	36%
	Mature	0.30	0.43	44%		0.033	0.161	393%		51.3	15.7	-69%
TSME												
	SSP	1.84	1.16	-37%		0.050	0.027	-46%		47.6	20.5	-57%
	Young	17.26	8.34	-52%		0.226	0.176	-22%		120.3	76.1	-37%
	Mature	8.94	18.48	107%		0.104	0.296	186%		77.2	80.0	4%
	Park-like	0.02	1.08	7127%		0.007	0.019	184%		4.0	158.9	3902%
	Old forest	0.86	1.36	59%		0.011	0.070	516%		182.2	39.7	-78%

Appendix B: Historical and current percentage area, patch density, and patch area of vegetation types on National Forest land in river basins of eastern Oregon and Washington. Historical years for assessment ranged from 1932-59; current years ranged from 1985-90. Area is expressed as the percentage of total basin area.

		Percent area				Patch density (n/km ²)				Mean patch area (ha)		
River basin & overstory cover	Structure ^a	H ^b	C	%D		H	C	%D		H	C	%D
GRANDE RONDE												
Agric/urban		0.63	0.14	-78%		0.048	0.007	-86%		43.4	20.2	-53%
Bare ground		1.78	2.08	17%		0.055	0.054	-2%		35.9	17.9	-50%
Water		0.28	0.12	-56%		0.041	0.032	-21%		17.0	19.7	16%
Grass/forb		14.95	9.21	-38%		0.289	0.389	35%		40.5	15.9	-61%
Shrub		0.70	0.76	8%		0.035	0.020	-44%		15.3	35.4	130%
PIPO	SSP	1.27	2.36	86%		0.042	0.135	221%		22.0	34.9	59%
	Young	0.59	6.72	1034%		0.014	0.275	1815%		13.7	32.7	139%
	Mature	5.39	2.72	-50%		0.154	0.209	36%		31.3	26.6	-15%
	Park-like	2.14	0.32	-85%		0.057	0.020	-66%		24.5	6.8	-72%
	Old forest	1.72	0.20	-88%		0.084	0.027	-68%		34.7	13.1	-62%
LAOC	SSP	0.80	0.28	-65%		0.028	0.022	-22%		29.6	17.6	-40%
	Young	0.49	2.61	431%		0.011	0.154	1290%		17.4	27.2	56%
	Mature	1.30	1.35	4%		0.042	0.121	188%		19.7	16.9	-14%
	Park-like	0.04	0.16	293%		0.008	0.020	165%		7.0	6.2	-11%
	Old forest	0.26	0.07	-74%		0.021	0.016	-53%		19.4	3.0	-84%
PICO	SSP	1.79	1.38	-23%		0.066	0.053	-20%		23.1	18.3	-21%
	Young	0.21	3.59	1627%		0.013	0.328	2478%		10.8	28.6	165%
	Mature	0.00	0.50	na		0.000	0.061	na		0.0	60.1	na
PSME/ABGR	SSP	11.06	3.86	-65%		0.448	0.199	-56%		24.7	52.4	112%
	Young	6.64	18.90	185%		0.175	0.802	358%		31.0	41.6	34%
	Mature	20.54	26.92	31%		0.525	0.766	46%		37.3	32.2	-14%
	Park-like	7.25	0.37	-95%		0.284	0.029	-90%		24.4	6.5	-74%
	Old forest	5.34	1.09	-80%		0.154	0.028	-82%		45.2	36.6	-19%
ABLA/PIEN	SSP	4.87	1.57	-68%		0.267	0.057	-78%		33.8	13.4	-60%
	Young	2.43	6.17	153%		0.120	0.166	38%		27.8	41.4	49%
	Mature	2.81	0.74	-74%		0.131	0.070	-47%		25.8	15.2	-41%
	Park-like	2.82	0.05	-98%		0.185	0.009	-95%		17.0	3.5	-80%
	Old forest	1.89	0.05	-97%		0.192	0.022	-89%		21.5	2.8	-87%
ABAM/TSHE	Young	0.00	0.07	na		0.000	0.011	na		0.0	57.6	na
PIAL/LALY	SSP	0.00	0.24	na		0.000	0.024	na		0.0	49.4	na
	Young	0.00	5.35	na		0.000	0.133	na		0.0	213.1	na
	Mature	0.00	0.04	na		0.000	0.016	na		0.0	23.6	na

Appendix B: Historical and current percentage area, patch density, and patch area of vegetation types on National Forest land in river basins of eastern Oregon and Washington. Historical years for assessment ranged from 1932-59; current years ranged from 1985-90. Area is expressed as the percentage of total basin area.

Current year range from 1990 to 2000											
		Percent area			Patch density (n/km ²)			Mean patch area (ha)			
River basin & overstory cover	Structure ^a	H ^b	C	%D	H	C	%D	H	C	%D	
METHOW											
Agric/urban		0.49	0.65	32%	0.037	0.048	29%	22.1	24.0	8%	
Bare ground		10.31	12.45	21%	0.104	0.174	67%	77.6	115.4	49%	
Water		0.01	0.12	789%	0.012	0.012	-1%	2.6	21.5	727%	
Grass/forb		2.02	2.38	18%	0.038	0.056	49%	55.6	38.4	-31%	
Shrub		1.74	5.89	239%	0.060	0.147	147%	54.6	27.3	-50%	
Hardwood		0.28	0.21	-26%	0.021	0.027	28%	23.9	8.7	-64%	
PIPO	SSP	1.62	1.91	18%	0.078	0.088	13%	44.7	50.5	13%	
	Young	0.76	3.53	367%	0.021	0.071	233%	59.5	41.1	-31%	
	Mature	2.62	3.77	44%	0.126	0.165	31%	77.3	75.6	-2%	
	Park-like	7.60	2.00	-74%	0.148	0.058	-61%	73.7	34.6	-53%	
	Old forest	4.92	0.60	-88%	0.092	0.028	-70%	125.9	40.1	-68%	
PIMO/PILA	SSP	0.18	0.00	-100%	0.022	0.000	-100%	70.0	0.0	-100%	
	Young	0.10	0.00	-100%	0.011	0.000	-100%	80.4	0.0	-100%	
	Park-like	0.09	0.00	-100%	0.022	0.000	-100%	36.9	0.0	-100%	
LAOC	SSP	0.06	0.11	88%	0.010	0.021	110%	13.2	13.6	3%	
	Young	0.00	0.08	na	0.000	0.020	na	0.0	52.1	na	
	Mature	0.56	0.65	15%	0.116	0.215	86%	63.3	39.2	-38%	
	Park-like	0.05	0.27	453%	0.007	0.039	443%	12.2	10.1	-17%	
	Old forest	0.48	0.56	17%	0.135	0.157	16%	46.3	46.8	1%	
PICO	SSP	7.46	5.24	-30%	0.072	0.049	-32%	63.2	60.7	-4%	
	Young	3.11	4.33	39%	0.099	0.113	14%	75.6	81.4	8%	
	Mature	0.00	0.11	na	0.000	0.016	na	0.0	133.9	na	
PSME/ABGR	SSP	1.80	2.15	19%	0.085	0.119	40%	27.9	21.7	-22%	
	Young	7.85	13.35	70%	0.117	0.292	150%	55.1	46.6	-15%	
	Mature	4.74	8.19	73%	0.081	0.156	94%	75.8	73.3	-3%	
	Park-like	3.34	1.99	-40%	0.079	0.106	34%	65.3	30.8	-53%	
	Old forest	4.99	2.27	-54%	0.055	0.069	26%	123.0	31.2	-75%	
ABLA/PIEN	SSP	4.21	2.69	-36%	0.080	0.075	-6%	47.5	39.0	-18%	
	Young	11.64	12.05	4%	0.181	0.260	43%	83.5	53.5	-36%	
	Mature	2.57	2.06	-20%	0.051	0.058	13%	54.4	51.7	-5%	
	Park-like	3.03	0.87	-71%	0.071	0.036	-49%	33.1	68.2	106%	
	Old forest	0.19	0.10	-47%	0.021	0.013	-36%	25.8	11.3	-56%	
ABAM/TSHE	SSP	0.97	0.28	-71%	0.120	0.046	-62%	41.9	32.6	-22%	
	Young	0.81	0.53	-35%	0.173	0.108	-38%	30.7	15.9	-48%	
	Mature	1.29	1.18	-9%	0.103	0.108	4%	49.2	35.6	-28%	
	Park-like	1.23	0.40	-68%	0.056	0.036	-35%	48.1	54.9	14%	
	Old forest	0.18	0.30	65%	0.078	0.117	50%	30.0	33.0	16%	
PIAL/LALY	SSP	4.52	4.33	-4%	0.104	0.135	30%	58.4	38.4	-34%	
	Young	2.01	2.35	16%	0.046	0.072	55%	41.6	40.1	-3%	
	Mature	0.09	0.05	-43%	0.015	0.017	-36%	32.3	17.1	-47%	

Appendix B: Historical and current percentage area, patch density, and patch area of vegetation types on National Forest land in river basins of eastern Oregon and Washington. Historical years for assessment ranged from 1932-59; current years ranged from 1985 to 1990. Area is expressed as the percentage of total basin area.

		Percent area				Patch density (n/km ²)				Mean patch area (ha)		
River basin & overstory cover	Structure ^a	H ^b	C	%D		H	C	%D		H	C	%D
PEND OREILLE												
Agric/urban		1.49	1.30	-13%		0.121	0.084	-31%		30.6	26.4	-14%
Bare ground		11.90	3.52	-70%		0.227	0.254	12%		160.8	13.6	-92%
Water		0.30	0.40	31%		0.018	0.055	196%		10.7	8.8	-17%
Grass/forb		0.22	0.89	300%		0.035	0.090	157%		6.2	24.7	296%
Shrub		0.20	0.36	84%		0.020	0.033	66%		10.9	9.9	-9%
Hardwood		0.09	0.30	235%		0.005	0.041	795%		3.8	7.8	106%
PIPO	SSP	1.79	0.90	-50%		0.065	0.055	-15%		25.4	11.4	-55%
	Young	8.41	1.83	-78%		0.233	0.058	-75%		23.1	23.3	1%
	Mature	0.67	2.40	258%		0.043	0.104	141%		16.0	24.3	52%
	Park-like	0.25	0.27	15%		0.012	0.021	69%		6.0	16.7	177%
PIMO/PILA	SSP	0.71	0.10	-86%		0.036	0.015	-59%		23.2	7.8	-66%
	Young	5.07	0.00	-100%		0.248	0.000	-100%		37.6	0.0	-100%
	Mature	1.61	0.00	-100%		0.154	0.000	-100%		24.1	0.0	-100%
LAOC	SSP	4.13	0.51	-88%		0.134	0.071	-47%		54.8	8.0	-85%
	Young	12.10	12.76	6%		0.257	0.634	147%		96.5	21.2	-78%
	Mature	2.16	0.64	-70%		0.102	0.041	-60%		14.7	16.6	13%
	Park-like	0.01	0.04	296%		0.005	0.009	99%		1.2	7.9	536%
PICO	SSP	8.41	4.01	-52%		0.238	0.222	-7%		22.6	23.7	5%
	Young	7.17	10.79	51%		0.196	0.555	183%		29.4	21.1	-28%
	Mature	0.15	0.57	286%		0.011	0.026	134%		7.1	34.8	391%
	Park-like	0.00	0.11	na		0.000	0.021	na		0.0	16.4	na
PSME/ABGR	SSP	3.78	8.43	123%		0.138	0.489	255%		44.6	17.3	-61%
	Young	18.23	21.57	18%		0.650	1.042	60%		32.2	19.5	-39%
	Mature	2.12	5.99	183%		0.113	0.222	97%		16.0	22.2	39%
	Park-like	0.54	1.70	215%		0.071	0.126	78%		10.0	23.7	137%
ABLA/PIEN	SSP	1.66	1.10	-33%		0.072	0.121	68%		11.5	11.6	1%
	Young	3.40	5.27	55%		0.158	0.315	99%		14.6	19.2	32%
	Mature	1.39	2.17	56%		0.057	0.110	93%		14.4	28.7	99%
	Park-like	0.29	0.68	138%		0.056	0.064	15%		6.2	18.1	193%
ABAM/TSHE	SSP	0.08	2.40	2934%		0.006	0.167	2621%		4.8	13.0	171%
	Young	0.38	5.70	1387%		0.005	0.367	7084%		21.2	14.7	-31%
	Mature	0.70	1.12	61%		0.020	0.085	326%		14.6	15.7	7%
	Park-like	0.41	2.06	404%		0.034	0.252	650%		14.0	15.5	11%
TSME	SSP	0.16	0.00	-100%		0.056	0.000	-100%		13.9	0.0	-100%
	Park-like	0.00	0.15	na		0.000	0.070	na		0.0	6.6	na

Appendix B: Historical and current percentage area, patch density and patch area of vegetation types on National Forest land in river basins of eastern Oregon and Washington. Historical years for assessment ranged from 1932-59; current years ranged from 1985-90. Area is expressed as the percentage of total basin area.

		Percent area				Patch density (n/km ²)			Mean patch area (ha)			
River basin & overstory cover	Structure ^a	H ^b	C	%D		H	C	%D		H	C	%D
WENATCHEE												
Agric/urban		0.25	0.22	-11%		0.044	0.039	-11%		19.8	20.4	3%
Bare ground		9.18	13.36	46%		0.182	0.392	116%		45.1	31.8	-30%
Water		0.72	0.47	-35%		0.100	0.050	-50%		11.5	11.8	2%
Grass/forb		0.97	1.91	97%		0.068	0.075	11%		14.5	28.7	98%
Shrub		6.78	6.55	-3%		0.164	0.168	2%		43.8	38.5	-12%
Hardwood		0.43	0.39	-18%		0.084	0.042	-50%		11.5	16.8	46%
PIPO												
	SSP	0.54	0.38	-30%		0.040	0.081	102%		31.4	11.1	-64%
	Young	0.78	0.19	-76%		0.071	0.040	-43%		21.4	8.5	-60%
	Mature	7.83	5.60	-28%		0.854	0.711	-17%		28.8	21.9	-24%
	Old forest	4.50	2.14	-52%		0.411	0.200	-51%		25.0	40.5	62%
	Park-like	1.64	2.32	42%		0.140	0.232	66%		35.2	24.2	-31%
PIMO/PILA												
	Young	0.02	0.00	-100%		0.008	0.000	-100%		17.0	0.0	-100%
	Mature	0.04	0.05	29%		0.017	0.008	-50%		17.0	43.8	158%
	Old forest	0.20	0.16	-21%		0.033	0.025	-25%		43.7	45.6	4%
	Park-like	0.07	0.00	-100%		0.008	0.000	-100%		60.5	0.0	-100%
LAOC												
	SSP	0.00	0.01	na		0.000	0.008	na		0.0	10.5	na
	Young	0.13	0.00	-100%		0.014	0.000	-100%		47.5	0.0	-100%
	Mature	0.14	0.01	-94%		0.096	0.011	-89%		10.6	5.2	-51%
	Old forest	0.46	0.00	-100%		0.096	0.000	-100%		34.3	0.0	-100%
PICO												
	SSP	0.30	0.29	-3%		0.018	0.024	38%		19.7	14.3	-27%
	Young	0.69	0.04	-95%		0.034	0.004	-88%		114.3	15.6	-86%
	Mature	0.11	0.00	-100%		0.012	0.000	-100%		53.9	0.0	-100%
PSME/ABGR												
	SSP	0.83	1.90	128%		0.061	0.119	94%		14.5	21.0	45%
	Young	2.59	1.64	-37%		0.096	0.089	-7%		23.7	29.4	24%
	Mature	11.02	12.56	14%		0.488	0.673	38%		33.9	28.2	-17%
	Park-like	1.06	2.39	140%		0.037	0.099	164%		36.5	30.4	-17%
	Old forest	6.89	7.58	10%		0.189	0.281	49%		55.5	33.7	-39%
ABLA/PIEN												
	SSP	2.97	2.36	-21%		0.122	0.119	-2%		22.2	19.1	-14%
	Young	13.83	10.39	-25%		0.290	0.308	6%		35.4	27.4	-23%
	Mature	12.32	5.16	-58%		0.251	0.173	-31%		27.3	27.5	1%
	Park-like	0.92	0.51	-44%		0.046	0.021	-55%		11.1	41.4	273%
	Old forest	2.66	2.49	-7%		0.044	0.049	12%		62.5	55.5	-11%
ABAM/TSHE												
	SSP	0.64	0.87	37%		0.104	0.102	-2%		16.1	18.2	13%
	Young	2.92	2.43	-17%		0.188	0.193	3%		20.4	18.6	-9%
	Mature	3.83	6.62	73%		0.178	0.267	50%		20.1	24.8	24%
	Park-like	0.44	0.66	52%		0.023	0.038	65%		8.3	19.2	132%
	Old forest	0.66	4.02	508%		0.030	0.131	332%		22.0	24.7	12%
TSME												
	SSP	0.00	0.11	na		0.000	0.086	na		0.0	6.5	na
	Young	0.00	0.19	na		0.000	0.057	na		0.0	17.1	na
	Mature	0.06	1.27	1930%		0.008	0.169	1934%		13.6	19.6	44%
	Park-like	0.00	0.16	na		0.000	0.043	na		0.0	19.6	na
	Old forest	0.05	0.71	1448%		0.008	0.072	762%		10.0	12.7	27%
PIAL/LALY												
	SSP	0.04	0.08	107%		0.012	0.015	32%		11.0	18.0	63%
	Young	0.54	1.55	186%		0.054	0.108	99%		13.8	36.6	166%
	Mature	0.03	0.25	715%		0.003	0.013	363%		8.7	33.9	288%

Appendix B: Historical and current percentage area, patch density and patch area of vegetation types on National Forest land in river basins of eastern Oregon and Washington. Historical years for assessment ranged from 1932-59; current years ranged from 1985-90. Area is expressed as the percentage of total basin area.

For current years ranged from 1986 to 2007. Area is expressed as the percentage of total basin area.												
River basin & overstory cover	Structure ^a	Percent area				Patch density (n/km ²)				Mean patch area (ha)		
		H ^b	C	%D		H	C	%D		H	C	%D
YAKIMA												
Agric/urban		0.20	0.58	191%		0.036	0.037	1%		29.4	77.8	165%
Bare ground		4.90	7.88	61%		0.134	0.248	85%		38.5	31.0	-20%
Water		1.39	1.27	-8%		0.048	0.040	-17%		72.6	52.0	-28%
Grass/forb		3.97	3.43	-14%		0.076	0.118	55%		31.3	32.3	3%
Shrub		0.18	0.23	24%		0.017	0.023	39%		14.1	12.3	-13%
Hardwood		0.06	0.00	-100%		0.017	0.000	-100%		11.2	0.0	-100%
PIPO												
	SSP	0.24	0.30	24%		0.006	0.035	453%		18.1	14.6	-19%
	Young	5.51	6.89	25%		0.115	0.146	27%		34.5	49.6	44%
	Mature	7.22	7.19	-0%		0.265	0.252	-5%		57.6	47.1	-18%
	Old forest	1.38	0.30	-78%		0.093	0.020	-79%		30.5	29.5	-3%
	Park-like	0.21	0.24	12%		0.010	0.014	33%		18.5	16.7	-9%
PIMO/PILA												
	SSP	0.03	0.17	522%		0.006	0.013	121%		9.0	21.7	142%
	Young	0.57	0.48	-16%		0.055	0.045	-18%		8.7	25.8	195%
	Mature	0.06	0.07	26%		0.012	0.012	-0%		36.0	45.2	26%
LAOC												
	SSP	0.00	0.00	na		0.000	0.009	na		0.0	2.9	na
	Young	0.67	0.35	-49%		0.032	0.029	-11%		33.2	11.9	-64%
	Park-like	0.01	0.00	-100%		0.012	0.000	-100%		9.5	0.0	-100%
	Mature	0.80	1.04	30%		0.046	0.059	30%		24.1	51.6	114%
PICO												
	SSP	0.17	0.40	140%		0.008	0.015	85%		17.3	35.3	104%
	Young	0.91	0.51	-45%		0.042	0.036	-13%		28.4	24.9	-12%
	Mature	0.11	0.05	-58%		0.004	0.004	-3%		34.3	17.0	-50%
PSME/ABGR												
	SSP	1.34	3.24	143%		0.032	0.123	279%		27.5	26.9	-2%
	Young	8.04	17.52	118%		0.197	0.397	102%		39.7	39.4	-1%
	Mature	24.72	17.24	-30%		0.307	0.291	-5%		68.8	54.7	-20%
	Park-like	1.37	0.76	-45%		0.034	0.043	26%		37.5	20.0	-47%
	Old forest	3.89	0.91	-77%		0.051	0.025	-50%		58.7	30.2	-49%
ABLA/PIEN												
	SSP	1.51	0.18	-88%		0.061	0.013	-78%		45.9	10.8	-76%
	Young	6.64	2.80	-58%		0.228	0.108	-53%		30.1	22.4	-26%
	Mature	2.36	2.16	-9%		0.066	0.066	1%		36.1	31.8	-12%
	Park-like	0.91	0.04	-95%		0.028	0.009	-67%		78.9	10.6	-87%
ABAM/TSHE												
	SSP	2.14	3.59	68%		0.047	0.176	278%		15.2	28.2	86%
	Young	3.85	8.20	113%		0.096	0.284	196%		37.8	34.5	-9%
	Mature	5.13	4.33	-16%		0.125	0.164	31%		41.8	48.1	15%
	Park-like	0.85	2.40	183%		0.075	0.183	143%		20.6	96.1	368%
	Old forest	6.15	0.51	-92%		0.143	0.028	-80%		169.1	40.3	-76%
TSME												
	SSP	0.15	0.01	-90%		0.010	0.004	-61%		37.8	3.0	-92%
	Young	0.45	0.37	-18%		0.032	0.026	-21%		18.8	33.0	75%
	Mature	1.25	1.55	24%		0.051	0.041	-20%		85.3	70.9	-17%
	Park-like	0.00	0.03	na		0.000	0.019	na		0.0	14.4	na
	Old forest	0.37	0.27	-29%		0.024	0.020	-16%		35.5	45.5	28%
PIAL/LALY												
	SSP	0.00	0.65	na		0.000	0.044	na		0.0	56.6	na
	Young	0.23	1.88	707%		0.021	0.038	78%		7.9	84.5	973%
	Mature	0.06	0.00	-100%		0.009	0.000	-100%		39.6	0.0	-100%

Appendix B. Definitions for table

a -

SSP = 1 canopy layer, seedling, sapling or pole trees (<23 cm diameter at breast height [dbh]);

Young - 2 canopy layers, overstory pole or young trees (13-41 cm dbh), understory saplings or poles (<23 cm dbh);

Mature - 2+ canopy layers, overstory mature trees (40-64 cm dbh), understory trees young or smaller (<40 cm dbh);

Mature park-like - 1 or 2 canopy layers, mature to old overstory trees (>40 cm dbh), understory trees absent or saplings (<13 cm dbh);

Old forest - 2+ canopy layers, overstory trees larger than mature (>64 cm dbh), pole to mature understory (13-64 cm dbh).

b - H = historic, C = current, and %D is percent change from historic.

c - Species codes:

PIPO= ponderosa pine

PIMO/PILA=white pine and sugar pine

LAOC= western larch

PICO=lodgepole pine

PSME/ABGR=Douglas-fir, grand fir, or white fir

ABLA/PIEN=subalpine fir and Engelmann spruce

ABAM/TSHE=Pacific silver fir, western hemlock, noble fir, Shasta red fir, or western red cedar

TSME=mountain hemlock

PIAL/LALY=whitebark pine and alpine larch.

d - percentage change from historic not available because historic value was zero.

Appendix C: Historical and current fuel loading, fire behavior, fuel consumption, emission factors, and smoke production for six river basins of eastern Oregon and Washington

Variable	Period	River basin					
		Deschutes	Grande Ronde	Methow	Pend Oreille	Wenatchee	Yakima
Forest fuels (Mg/ha)	Historical	85.06	84.5	75.33	83.98	98.09	102.65
	Current	92.95	83.27	75.28	85.33	92.89	90.97
	Change	7.89	-1.23	-0.04	1.35	-5.2	-11.68
Fuel consumption Wildfires (Mg/ha)	Historical	56.31	48.39	48.05	53.77	55.16	57.34
	Current	57.34	52.31	49.64	53.7	51.71	54.85
	Change	1.03	3.93	1.59	-0.07	-3.45	-2.49
Prescribed fires (Mg/ha)	Historical	37.24	31.43	30.89	36.14	33.92	35.96
	Current	37.32	34.59	32.17	35.08	31.97	35.2
	Change	0.08	3.16	1.28	-1.05	-1.95	-0.76
Fire rate of spread (m/min)	Historical	2.08	4	2.21	1.72	1.5	1.9
	Current	2.19	3.21	2.11	1.91	1.77	2.27
	Change	0.11	-0.79	-0.1	0.19	0.27	0.37
Flame length (m)	Historical	1.12	1.14	0.95	1.19	0.98	1.09
	Current	1.06	1.25	0.96	1.12	0.96	1.16
	Change	-0.06	0.11	0.02	-0.07	-0.02	0.08
Fire resistance to suppression (m/man-min.)	Historical	0.66	0.64	1	0.55	0.73	0.61
	Current	0.62	0.64	0.97	0.6	0.89	0.67
	Change	-0.04	0	-0.03	0.05	0.16	0.06
Smoke emission factors							
PM10 Prescribed fires (g/kg)	Historical	10.96	10.28	10.8	11.31	10.46	10.42
	Current	10.89	10.76	10.87	11.02	10.57	10.53
	Change	-0.06	0.48	0.06	-0.29	0.11	0.11
PM10 Wildfires (g/kg)	Historical	14.09	12.73	13.72	14.56	13.23	13.3
	Current	13.93	13.56	13.85	14.16	13.35	13.47
	Change	-0.15	0.83	0.13	-0.39	0.12	0.17
Smoke production PM10							
Prescribed fires (kg/ha)	Historical	409	323.6	332.54	408.34	354.5	375.15
	Current	408	371.93	349.23	386.04	338.04	371.44
	Change	-1	48.33	16.69	-22.3	-16.45	-3.71
Wildfires (kg/ha)	Historical	793.07	622.06	656.87	781.1	730.19	762.93
	Current	799.19	711.71	686.37	759.31	690.94	739.82
	Change	6.12	89.65	29.5	-21.79	-39.25	-23.11

Appendix D: List of common and scientific names and abbreviations

Common Name—Abbreviation	Scientific name
Annosum root disease	<i>Heterobasidion annosum</i> (Fr.) Bref.
Armillaria root disease	<i>Armillaria ostoyae</i> (Romag.) Herink
Douglas-fir—PSME	<i>Pseudotsuga menziesii</i> (Mirb.) Franco
Douglas-fir tussock moth—DFTM	<i>Orgyia pseudotsugata</i> (McDunnough)
Douglas-fir beetle—DFB	<i>Dendroctonus pseudotsugae</i> Hopkins
Douglas-fir dwarf mistletoe—DFDM	<i>Arceuthobium douglasii</i> Engelm.
Engelmann spruce—PIEN	<i>Picea engelmannii</i> Parry ex Engelm.
Fir engraver—FE	<i>Scolytus ventralis</i> LeConte
Goshawk	<i>Accipiter gentilis</i>
Grand fir—ABGR	<i>Abies grandis</i> (Dougl. ex D. Don) Lindl.
Laminated root rot	<i>Phellinus weirii</i> (Murr.) Gilb.
Lodgepole pine dwarf mistletoe—LPDM	<i>Arceuthobium americanum</i> Nutt. ex Engelm.
Lodgepole pine—PICO	<i>Pinus contorta</i> Dougl. ex Loud. var. <i>latifolia</i> Engelm
Mountain hemlock - TSME	<i>Tsuga mertensiana</i> (Bong.) Carr.
Mountain pine beetle - MPB	<i>Dendroctonus ponderosae</i> Hopkins
Noble fir—ABPR	<i>Abies procera</i> Rehd.
Pacific silver fir—ABAM	<i>Abies amabilis</i> Dougl. ex Forbes
Pandora moth	<i>Coloradia pandora</i> Blake
Pine butterfly	<i>Neophasia menapia</i> (Felder and Felder)
Pine marten	<i>Martes americana</i>
Ponderosa pine—PIPO	<i>Pinus ponderosa</i> Dougl. ex Laws.
Shasta red fir—ABMA	<i>Abies magnifica</i> A. Murr.
Spruce beetle	<i>Dendroctonus rufipennis</i> Kirby
Subalpine fir—ABLA	<i>Abies lasiocarpa</i> (Hook.) Nutt.
Subalpine larch—LALY	<i>Larix lyallii</i> Parl.
Western spruce budworm—WSB	<i>Choristoneura occidentalis</i> Freeman
Western redcedar—THPL	<i>Thuja plicata</i> Donn ex D. Don
Western hemlock—TSHE	<i>Tsuga heterophylla</i> (Raf.) Sarg.
Western larch—LAOC	<i>Larix occidentalis</i> Nutt.
Western larch dwarf mistletoe—WLDM	<i>Arceuthobium laricis</i> (Piper) St. John
Western dwarf mistletoe—PPDM	<i>Arceuthobium campylopodum</i> Engelm.
Western pine beetle—WPB	<i>Dendroctonus brevicornis</i> LeConte
Western white pine—PIMO	<i>Pinus monticola</i> Dougl. ex D. Don
Whitebark pine—PIAL	<i>Pinus albicaulis</i> Engelm.
White fir—ABCO	<i>Abies concolor</i> (Gord. & Glend.) Lindl. ex Hildebr.

Appendix E: Historical and current maps of overstory vegetation structure/age classes for selected sample watersheds

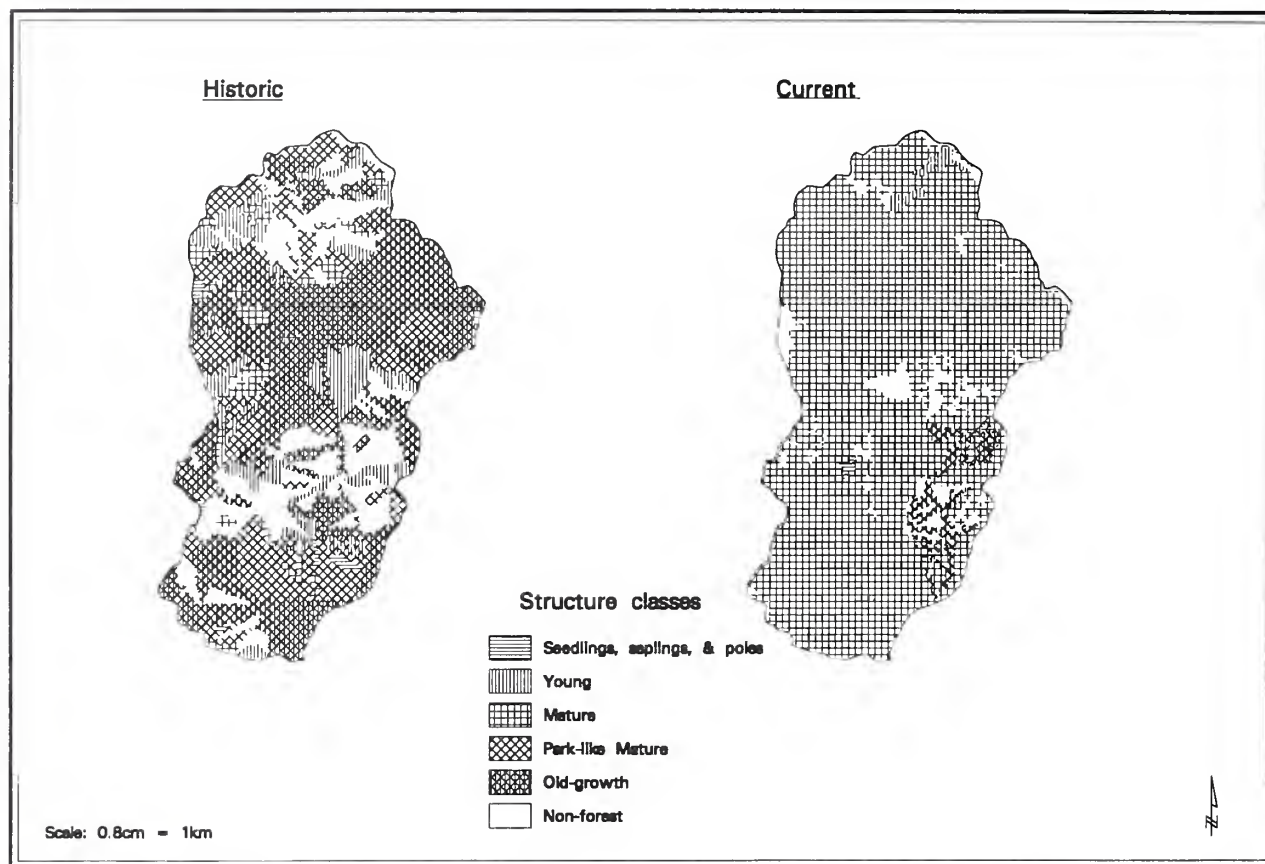


Figure 1—Historical and current maps of overstory vegetation structure/age classes for sample watershed 55 in the Grande Ronde River basin, eastern Oregon.

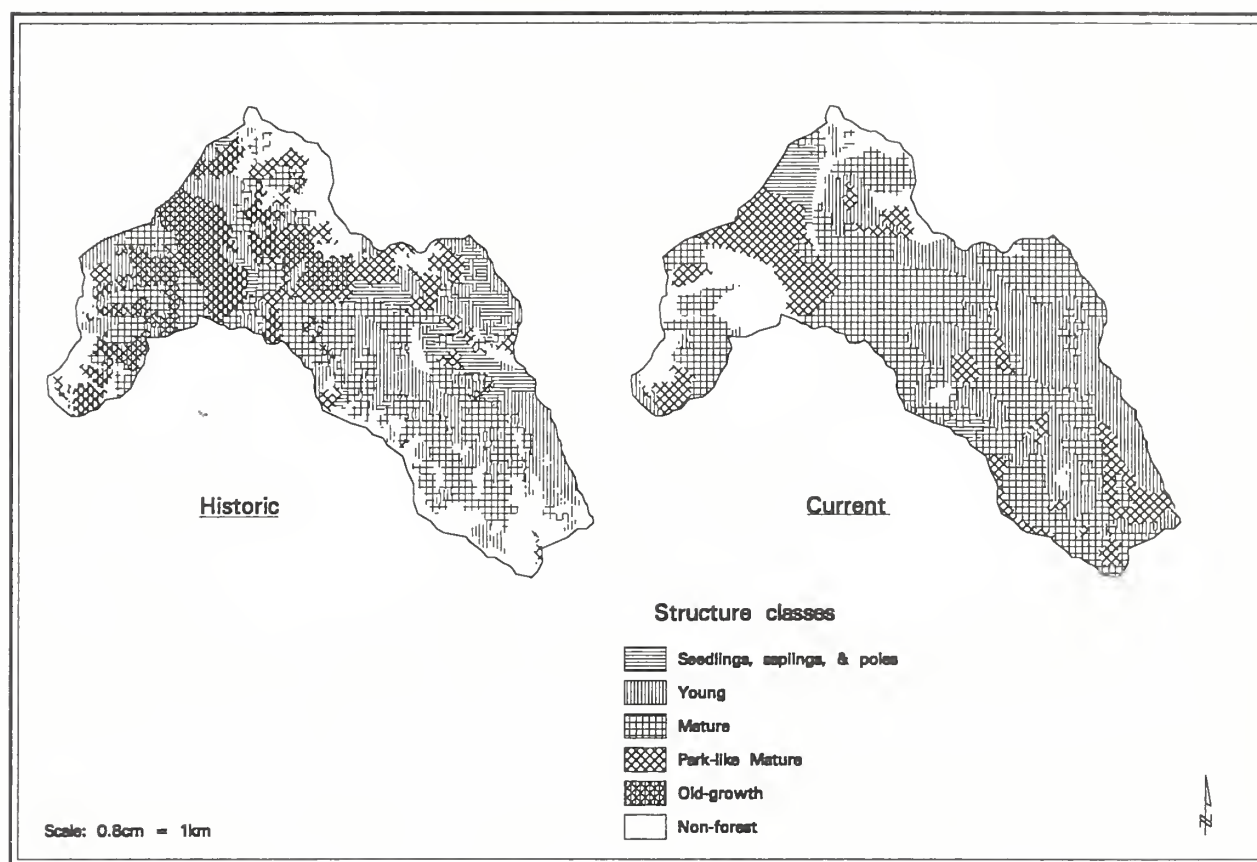


Figure 2—Historical and current maps of overstory vegetation structure/age classes for sample watershed 35 in the Grande Ronde River basin, eastern Oregon.

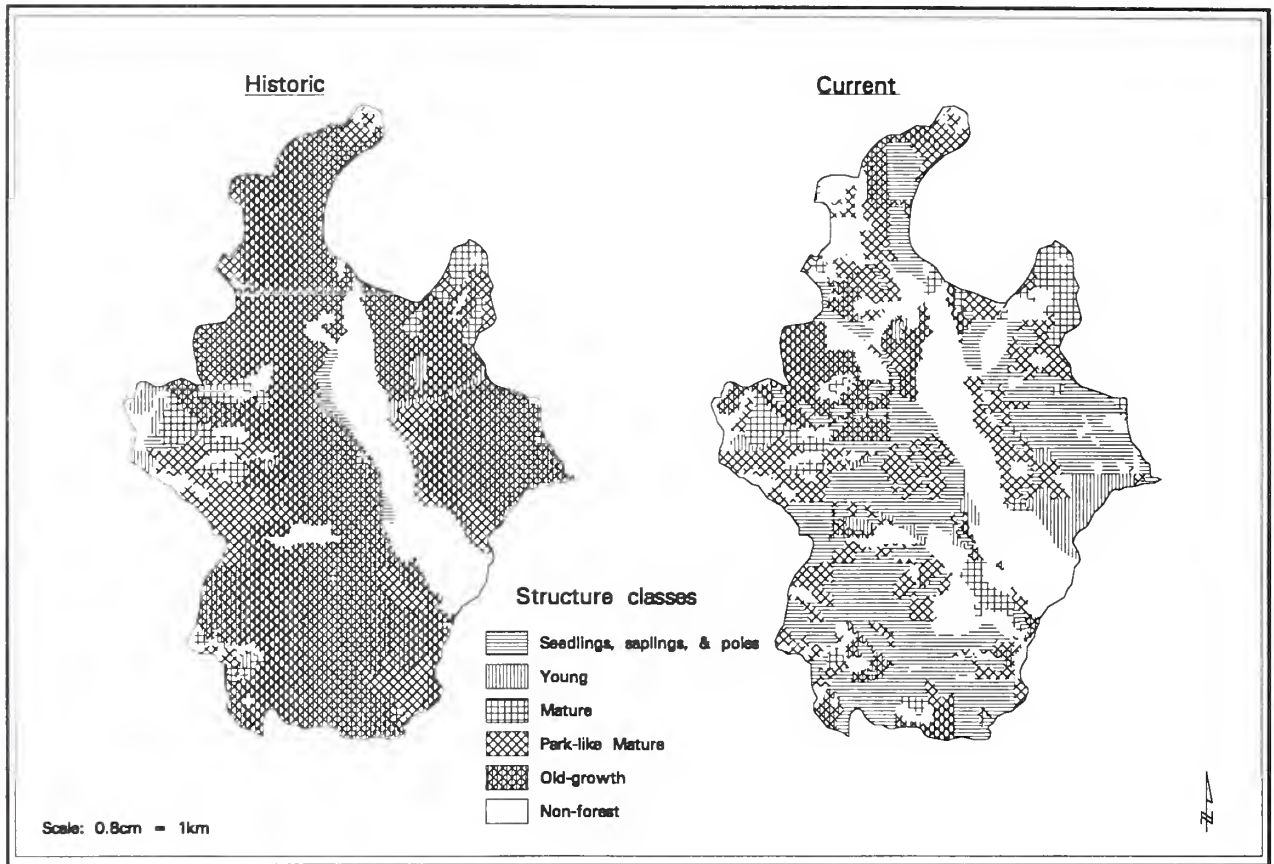


Figure 3—Historical and current maps of overstory vegetation structure/age classes for sample watershed 30 in the Yakima River basin, eastern Washington.

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GLOSSARY

A1 horizon—Surface soil layer with maximum organic matter accumulation.

AC horizon—A transitional layer in a young soil occurring between a weathered horizon with organic matter accumulation and an unweathered horizon with very little organic matter.

Acclimative trait—Ability of a tree to adjust a trait to match the environment, based on physiological rather than genetic processes.

Achlorophyllous plants—Plants that lack chlorophyll and cannot produce their own food.

Adaptive management—Implementing management decisions as experiments, whose results are used to modify management policy.

Advance regeneration—Trees of certain shade tolerant species which can remain alive as seedlings or saplings but grow very little until larger overstory trees are removed.

Adventitious—Additional; occurring in unusual or abnormal positions, as adventitious roots or buds.

Aggradation—Deposition in one place of material eroded from another. Aggradation raises the elevation of streambeds, floodplains, and the bottoms or other water bodies.

Alfisols—Soils with moderate to high base saturation and a clay horizon.

Alien (or Exotic) species—Species of fish or wildlife that were deliberately or accidentally introduced in an ecosystem and that have become permanently established; alien species often, but not always, have undesirable effects on native species; called “non-native species” in National Forest Management Act regulations (36 CFR 219).

Alien (plant)—A species occurring in an area to which it is not native, i.e., one introduced very recently, and usually by man.

All-sided LAI—Surface area of needles in m^2/m^2 of ground surface.

Allotment (grazing)—Area designated for the use of a prescribed number and kind of livestock under one plan of grazing management.

Allowable Use—The degree of utilization considered desirable and attainable on various parts of a ranch or allotment considering the present nature and condition of the resource, management objectives, and the level of management.

Alluvial—Deposited by running water.

Alluvium—Sand, mud, and other sediments deposited on land by streams.

Alpine glacier—A mass of ice occupying a depression within, or lying on mountainous terrain.

Amelioration—An action designed to repair or minimize specific damages.

Ammonia volatilization—During the fermentation process of digestion by hooved mammals, ammonia is released as a gas.

Ammonification—Conversion of other forms of nitrogen into derivatives of ammonia. This form of nitrogen is not leached from the soil and is highly available for plant use.

Anadromous—Moving from the sea to fresh water for reproduction.

Andesites—Dark, gray rocks, consisting essentially of oligoclase or feldspar with augite, hornblende, hypersthene or biotite.

Andesitic—Pertaining to andesite, a gray to grayish-black, fine-grained volcanic rock.

Andosols—Volcanic ash influenced inceptisols.

Animal Unit Equivalent—an index that refers to the potential for forage removal by various classes of livestock; an animal unit equivalent = 1 horse, a domestic cow with her calf, or 5 domestic sheep.

Animal Unit Month (AUM)—Amount of feed or forage required by one animal-unit grazing on a pasture for 1 month. An animal-unit is one mature (454-kg) cow or the equivalent of other animals, based on an average daily forage consumption of 12 kg dry matter. An AUM is also defined as 1-month tenure of one animal-unit.

Animal-unit (stock unit)—Considered to be one mature (1,000 pound) cow or the equivalent.

Anthropogenic—Caused by human activities.

Aquifer—A saturated permeable material (often sand, gravel, sandstone, or limestone) that contains or carries groundwater.

Armor layer—Erosion-resistant layer of relatively large particles on the surface of a streambed. Such layers typically result from removal of finer particles by erosion

Arthropods—Members of the largest phylum in the animal kingdom, including insects, arachnids (spiders, ticks, and mites), myriapods (centipedes, millipedes, and the like), and crustaceans (lobsters, shrimp, crabs, barnacles, and the like).

Aspect—The direction a slope faces.

Assimilation—Act of absorbing nutrients, carbon, etc., into a plant body.

Avoider—A survival strategy of plants poorly adapted to fire to avoid the lethal effects of fire.

B.P.—An abbreviation for Before Present. Used with radiocarbon age estimates. A.D. 1950 is the standard zero point. See tree-ring corrected and radiocarbon age.

Balance point—In reference to carbon, where carbon fixed (photosynthesis) and carbon used (respiration) are in balance.

Bankfull width—Stream channel width between the tops of the most pronounced banks on either side of a stream reach. Also, width of stream channel at the normal flood flow.

Bark beetles—Beetles (Coleoptera/Scolytidae) that attach tree stems and produce their young in galleries located between the outer wood and inner bark.

Basal area—Cross-sectional area of stems at breast height (4.5 feet).

Basalt—Volcanic rock that is hard, heavy, and dark.

Base concentration—Quantity of base-reacting plant nutrients.

Base flow—Typical flow for a given stream at a particular time of year.

Basin (river drainage area; catchment)—The area of land that drains water, sediment and dissolved materials to a common point along a stream channel.

Bed load—Sediment moving on or near a streambed.

Biodiversity (biological diversity)—The variety of living organisms and their processes.

Biomass—The sum total of living plants and animals above and below ground in an area at a given time.

Broadcast burning—Burning forest fuels as they are; no piling windrowing, etc.

Brooms or witches-brooms—Abnormally dense clusters of shoots or branches on conifers caused by infection by dwarf mistletoes and certain needlecast or rust fungi.

Browsing—Browsing and grazing are used interchangeably.

Bulk density—Weight of soil per unit volume, usually expressed in g/cc, e.g. volcanic ash soil (0.6g/cc), glacial till soil (1.0g/cc). Soils with a density over 1.0g/cc are generally considered dense enough to impede root penetration.

Bull:Cow:Calf Ratio—The ratio used to monitor sex and age composition of a big game population.

Butt rot—Internal wood decay caused by fungi in the base (butt) of a tree.

Calf recruitment—The number of elk calves which survive their first year of life to enter the yearling age class, a product of the number of live births and the calf survival rate, and often expressed in terms of calves recruited per 100 cows.

Canker—A disease symptom in which there is a sharply-limited death of cortical tissues (living inner bark) on branches or trunks of trees.

Canopy—The part of any stand of trees represented by the tree crowns; canopies may occur in layers.

Canopy cover (of streams)—Vegetation projecting over a stream, including crown cover and overhanging cover species.

Carbon deficit—Insufficient carbon (photosynthate) to support essential plant respiration and growth functions.

Carrying capacity—A measure of the number of animals that can be maintained over a specified period of time on a specified amount of land. Ecological carrying capacity refers to the number of animals that can be supported irrespective of how productive the animals are, whereas economic carrying capacity refers to the number of animals that can be supported at maximum levels of productivity.

Cation exchange capacity—Capacity of soil to attach specific quantities of cation-based nutrients to electrically charged surfaces.

- Channelization of streams**—Human-caused alterations to the stream channel that cause the channel to be fixed in place, such as levees, dikes, trenching, and rip-rap.
- Chlorophyllous hosts**—Plants that produce chlorophyll and thereby, some or all of their food requirements.
- Clearcut**—An area of forest from which all merchantable trees have been removed by harvesting.
- Clearcutting**—A regeneration harvest method whereby all trees (with the exception of advance regeneration) are removed from an area of the forest.
- Climatic climax**—A climax condition that is maintained by climatic factors such as temperature and precipitation regimes, and length of growing season; compare with edaphic climax.
Climax—The terminal, theoretically stable, self-perpetuating condition in a series of plant communities that culminates plant succession on any given site in the absence of any major disturbance.
- Climax species (or series)**—The tree species predominating on a site at climax especially in the absence of major disturbances. Sites are often described in terms of the major forest series they belong to (example—grand fir climax series, which includes plant associations where grand fir is the dominant overstory species at climax).
- Climax vegetation**—The pattern or complex of climax plant communities on a landscape corresponding to the pattern of environmental gradients or habitats.
- Coarse filter management**—Conservation of land areas and representative habitats under the working hypothesis that the needs of all associated species, communities, environments, and ecological processes will be met; compare with Fine Filter Management.
- Cohesion**—The ability of soil particles to attract one another, e.g. those with high cohesion resist erosion; those with low cohesion are highly erodible.
- Cohort**—Trees of an area regenerating after a single common disturbance event. Cohort is used interchangeably with “age class”.
- Colluvium (colluvial)**—Unconsolidated rock detritus and soil deposited on or at the base of steep slopes by mass wasting (direct gravitational action) and local unconcentrated runoff.
- Colonization**—The process of plant population establishment on a recently bared soil surface.
- Commensurability**—A term that is used to describe a private ranching operation that has the capacity to provide for livestock when they are not grazed on public lands.
- Compacted tills**—Soils derived from glacial deposits; these soils were overlain by glaciers and the weight of ice severely compacts them, usually sufficient to make them resistant to root penetration.
- Compaction**—The act of increasing bulk density of the soil. Compacted soils usually have reduced ability to support vigorous vegetation because of reduced water and air permeability, and reduced root penetration.
- Competition**—An interaction that occurs whenever two or more living organisms make demands of an ecosystem that are in excess of supply.
- Connectivity (of habitats)**—The linkage of similar but spatially separated vegetation stands (such as mature forests) by patches, corridors, or “stepping stones” of like vegetation across the landscape; also, the degree to which similar habitats are so linked.

- Constrained**—A narrow valley limited in width by adjacent landforms, with a valley floor width less than two active channel widths. Valley walls are usually steep and streams cannot meander.
- Continental ice sheets**—Glaciers occupying a large part of a continent. See Cordilleran and Laurentide.
- Continuum**—An abstract concept to describe plant and vegetation distributions. Plant species have different environmental requirements. Since environmental factors vary continuously in time and space, vegetation can be described as a continuous variable. Plant distributions form a continuum of variability, not discrete communities.
- Controlled fire**—(Same as prescribed fire). A human-caused fire, intentionally set under controlled conditions, such that the area burned, the amount of smoke generated, and the intensity of fire can be controlled.
- Cordilleran ice sheet**—A continental ice sheet which formed along the northern Rocky Mountains and spread eastward during the last part of the Pleistocene some 75,000 to 10,000 years ago.
- Couplets**—A pair of sedimentary layers in lake deposits which represent related deposits. In the case of charcoal and ash deposits in a sediment core, the couplets represent the settling out of the heavier particles before the finer particles from a single fire event.
- Cover**—Any feature that provides protective concealment for fish and wildlife. Cover may consist of live or dead vegetation, or geomorphic features such as boulders and undercut banks. Cover may be used for the purposes of escape from predators, feeding, or resting.
- Coverage**—The area of ground covered in a vertical projection of individual plant canopies.
- Coverts**—Animal habitat focal points—locations in the forest where three or more different patch types converge.
- Crown**—The part of any tree containing live foliage.
- Crown fire**—A fire burning into the crowns of the vegetation, generally associated with an intense understory fire.
- Cryandepts**—Soils developing in volcanic pumice and ash having a mean annual ambient temperature between 37° and 46.4°F.
- Cumulative effects**—Effects on the environment resulting from individual events that become collectively-significant over a period of time.
- Cumulative effects analysis**—The prediction of cumulative effects through modeling and analysis (see Cumulative Effects).
- Cytokinins**—Any of a group of plant growth-regulating substances that regulate cell division.
- Debris (organic)**—Logs, trees, limbs, branches, leaves, bark that accumulate, often in streams or riparian areas. Debris may be naturally occurring or the result of man's activities.
- Debris torrent failure**—A mass of rock, soil, and other debris that has moved rapidly downslope; because of high water content it has behaved like a water torrent or avalanche.
- Decay**—The decomposition of wood and the corresponding changes in physical and chemical properties; usually caused by fungi.

- Deferred rotation grazing**—A livestock grazing system that schedules grazing annually to avoid back-to-back grazing, thereby allowing range recovery.
- Defoliating insects**—Insects which feed on leaves or needles of living trees.
- Defoliator**—An insect that feeds on tree foliage.
- Deglaciation**—The uncovering of an area beneath glacier ice as the result of melting (wasting).
- Degradation**—Erosional removal of materials from one place to another. Degradation lowers the elevation of streambeds and floodplains.
- Density-dependence**—A term that suggests that factors that depress the growth rate of populations increase in effect as population density increases.
- Density-dependent**—The action of repressive environmental factors on one or more aspects of animal population performance, which intensify as animal density increases and relax as animal density declines.
- Depauperate**—Said of stands with sparse ground covering vegetation due to—1) tree overstory density precluding sufficient light for understory plant growth, 2) a deep and restrictive litter or duff layer, or a combination of limiting site factors.
- Dietary composition**—Refers to the combination of items (plant species in the case of herbivores) present in an animal's diet.
- Diploxylon**—A subgenus of *Pinus* lacking conspicuous verrucae on the pollen grain distal membrane; includes lodgepole and ponderosa pine.
- Discharge**—Water flow rate, often expressed in terms of the volume of water flowing by a reference point per unit of time (e.g., m³/sec).
- Disclimax**—A type of climax community that is maintained by either continuous or intermittent disturbance (i.e. - grazing, burning, logging) to a severity that the natural climax community is altered.
- Disease (plant)**—Any harmful deviation within a plant that interferes with normal structure, function, or value; often caused by pathogenic fungi and bacteria.
- Displacement**—The act of physically moving soil horizons off site, essentially rendering soil components unavailable to future vegetation.
- Disseminule**—A detached structure capable of reproducing a plant.
- Disturbance**—Any event which alters the structure, composition, or function of terrestrial or aquatic habitats.
- Dominant**—A group of plants that by their collective size, mass, or number exert a primary influence on other ecosystem components.
- Dry ravel**—Movement of dry soil material downslope.
- Duff**—The surface layer of the forest floor consisting of freshly fallen and partially decomposed leaves, needles, twigs, stems, bark, and fruits.

- Dynamic equilibrium**—An ongoing process involving interactions and adjustments whereby the growth rates of herbivores and their forage species are in a state of relatively stable balance.
- Early spacing**—Intentional spacing of trees in young, overcrowded stands whereby some trees are removed to improve growing conditions for residual trees; also called precommercial thinning.
- Ecological indicator species**—A species whose population size and trend is assumed to reflect the population sizes and trends of other species associated with the same geographic area and habitats; one type of management indicator species (see Management Indicator Species).
- Economic feasibility**—A measure of the capacity of an action to provide a reasonable rate of return on investment.
- Ecosystem**—A complete interacting system of organisms considered together with their environments. A biotic community and its abiotic environments.
- Ecosystem management**—Conservation and use of natural resources to maintain biological diversity, long-term site productivity, and sustainable resource production and use; the new management paradigm on National Forests.
- Ecotone**—See Habitat Edge.
- Ectomycorrhiza (pl. ectomycorrhizae)**—A symbiotic relationship involving the growth of a fungal mycelium on and within small roots of higher plants; many conifer mycorrhizal associations are ectomycorrhizal. Mycorrhiza literally means ‘fungus root’; ecto- implies that the interaction takes place in the outer cortex.
- Edaphic climax**—A climax that is the result of unique soil conditions usually differing from those of the surrounding area.
- Edaphic controls**—A term applied to any soil characteristic that affects plant growth.
- Edge**—See Habitat Edge.
- Either-sex hunt**—A hunting season in which hunters are allowed to harvest either a male or female animal.
- Embeddedness**—Degree to which large particles (boulders, rubble, gravel) are surrounded or covered by fine sediment, usually measured in classes according to percent coverage.
- Endemic**—Said of an organism that is restricted to a particular area or region under normal circumstances of environment.
- Epidemic or outbreak**—Pertaining to pathogen or insect populations that affect large numbers of a host population at the same time, often disturbing processes and interactions within forested stands and landscapes to the point of causing economic or habitat losses.
- Endurer**—A survival strategy of plants that enables them to resprout or otherwise endure the effects of fire.
- Evader**—A survival strategy of plants that enables them to evade harmful effects of fire by storing long-lived propagules in soils or canopies.

- Evapotranspiration**—The continuous process of water conduction through plants is powered by evapotranspiration; water is taken up by roots, translocated through stems to leaves, and transpired and evaporated at leaf surfaces.
- Even-aged systems**—Silvicultural and harvest systems that propagate and perpetuate predominantly same-age or single cohort stands of trees. Even-aged systems include clearcut, seed tree, and shelterwood systems.
- Exclosure**—Area from which livestock or other animals are excluded.
- Exotic**—A plant or animal species introduced from a distance place, usually another country.
- Exotic species**—See Alien Species.
- Fauna**—the vertebrate and invertebrate animals of an area or region.
- Featured species**—A species of fish or wildlife for which specific management guidelines have been written.
- Fecundity**—A specific statistic in population dynamics that refers to the average number of offspring produced per reproducing female in a population.
- Feeder root pathogens**—Pathogens that attack the small (less than 2mm) fibrous plant roots that are responsible for water and nutrient uptake.
- Fertilization**—Application of nutrients to forest stands to enhance tree growth or to correct for nutrient deficiencies.
- Fine filter management**—Management that focuses on the welfare of a single or few species rather than broad management of an habitat or ecosystem (see Coarse Filter Management).
- Fire cycle**—The average time between fires in a given area.
- Fire frequency**—The return interval of fire.
- Fire predictability**—A measure of variation in fire frequency.
- Fire regime**—The frequency, predictability, intensity, seasonality, and extent characteristics of fires in an ecosystem.
- Fire severity**—The effect of fire on plant communities. For trees, it is often measured as the percentage of basal area killed by fire.
- Fireline intensity**—The rate of heat release along a unit length of fireline, measured in kW m^{-1} .
- Flagship species**—A highly charismatic wildlife species, typically a large-bodied mammal or bird, that is in some peril of extirpation, and that can be managed so as to also provide habitats and resources for other species; compare with Umbrella Species.
- Floodplain**—Level lowland bordering streams onto which streams spread at flood stage.
- Fluvial**—Pertaining to or produced by the action of a stream or river.

Foehn wind—A wind flowing down the leeward side of mountain ranges where air is forced across the ranges by the prevailing pressure gradient.

Forb—An herbaceous plant that is not a sedge, grass, or other plant with grass-like foliage.

Forest floor—Organic horizons overlaying a mineral soil base; in forests, includes plant organic litter (leaves, small stems, etc.), humus, and soil wood.

Forest health—A measure of the robustness of forests in terms of their biological diversity, soil, air, and water productivity, disturbance ecology, and capacity to supply a sustainable flow of goods and services for humans.

Fragmentation—See Habitat Fragmentation.

Frass—Solid excrement from insect larvae such as defoliators; also wood fragments made by wood-boring insects (often beetles) usually mixed with excrement.

Free-living—Capable of living free in bulk soil without dependence on plant infection for survival.

Fuel—Dry, dead tree parts which can readily burn.

Fungus, pl. fungi—Any of a vast number of microscopic seedless plants (cryptogams), not including bacteria, that are usually filamentous, lack chlorophyll and vascular tissues, and ordinarily reproduce by spores.

Gallery—A tunnel or pathway, usually in tree bark or wood, in which an insect lives, feeds, and/or reproduces.

Game—Traditionally, animal species that are hunted for sport or food.

General hunt—A hunting season in which the total number of hunters is not limited by administrative rules or regulation.

Geomorphology—The geological study of land form evolution and configuration.

Glacial Lake Missoula—A Pleistocene proglacial lake which formed when glacial melt water was trapped behind an ice dam on the Clark Fork River in northwestern Montana. The lake filled and emptied many times. The deeply eroded landscape of central Washington state (scablands) was formed by catastrophic releases of water from this lake.

Glacial till—Unstratified glacial drift consisting of clay, sand, gravel, and boulders intermingled.

Graded beds—An arrangement of sediment layers in which each layer displays a gradual change in particle size, usually from coarse at the bottom to fine at the top.

Gradient—The rate of vertical elevation change per unit of horizontal distance—also known as slope.

Graminoid (gramineous)—A herbaceous grass or grass-like plant.

Grazing—Grazing and browsing are used interchangeably.

Ground fire—A fire that burns along the forest floor, and does not affect trees with thick bark or high crown bases.

Growth respiration—Respiration that directly supports plant growth, as opposed to that required to support maintenance of an existing plant body.

Guild—A group of species that share a common habitat (such as old-growth forests), that use the same resources (such as foods), or that use resources in the same manner (such as mode of foraging).

Guild indicator—Alternate name for indicator guild (see Indicator Guild).

Habitat—The area where a plant or animal lives and grows under natural conditions. Habitat consists of living and non-living attributes, and provides all requirements for food and shelter.

Habitat edge—The margin where two or more vegetation patches meet, such as the boundary of a clearcut next to a mature forest stand; also see Habitat Fragmentation.

Habitat fragmentation—The splitting or isolating of patches of similar habitat, typically forest cover (but could also apply to grass fields, shrub patches, and other habitats); habitat can be fragmented from natural conditions, such as thin or variable soils, or from forest management activities, such as clearcut logging.

Habitat interior species—See Unitype Species.

Habitat type—The land area capable of supporting a single plant association.

Haploxyton—A subgenus of *Pinus* with conspicuous verrucae on the pollen grain distal membrane. Includes white pines such as limber pine and whitebark pine.

Harvest—Felling and removal of tree stems from the forest for the manufacture of forest products.

Harvest systems—Patterns of tree removal that mimic aspects of partial or complete stand-replacing disturbances.

Harvestable surplus—The number of game animals or fish that can be removed from a population, typically by hunting or fishing, that will not cause the population to unduly decline; sustainable harvestable surplus is the number that can be removed every year or harvest season for an indefinite period of time.

Haul—Transport harvested tree stems (logs) from a forest where they were felled and yarded, to a processing location (mill).

Headwater (headwall)—steep slope at the head of a valley.

Heart rot—Wood decay that is apparently restricted to heartwood.

Heartwood—The interior wood in living trees that provides strength and rigidity to stems, has ceased conducting water and nutrients, contains no living cells, and is generally darker in color than wood to the exterior.

Heat capacities—The amount of heat required to raise the temperature of one gram of soil one degree.

Herb—Non-woody vegetation that includes both grasses and broad-leaf plants of low profile, known as forbs.

High grading—Uneven-aged harvest systems where the most valuable trees and species are removed, and trees of lesser value and quality are left to grow.

- Holocene**—An epoch of the Quaternary period. It began about 10,000 years ago and continues to the present time.
- Humus**—Highly decomposed soil organic matter, usually black in color and decomposed to the point that the original source is no longer identifiable.
- Hydraulic mining**—Use of high-pressure water jets to erode ore-bearing alluvial deposits.
- Hydrograph**—Stream flow profile.
- Hyphae**—Individual fungal strands or filaments.
- Hypsithermal**—In eastern north America, a part of the Holocene (about 9000 to 2500 B.P.) during which climatic conditions were thought to be warmer than earlier or later times.
- Immobilization**—The process of binding plant nutrients into organic compounds; when so bound they cannot move within the soil profile and are not available for plant use.
- Inceptisols**—Soils having altered horizons that have lost bases or iron and aluminum, but retain weatherable minerals, and do not have horizons enriched with silicate clays or mixtures of aluminum and organic carbon.
- Indicator guild**—A set of species sharing a common habitat to which management guidelines can be directed; it is often erroneously assumed that all species of an indicator guild respond identically to management activities and environmental conditions.
- Indicator species**—See Management Indicator Species and Ecological Indicator Species.
- Indicator species**—A species that is presumed to be sensitive to spatial or temporal variation of vegetation such that its constancy or abundance reflects changes in abiotic or biotic environmental factors.
- Individualized process model**—A physiological process model designed to simulate growth and development of individual plants.
- Infection**—The establishment of a parasite (usually fungal or bacterial) within a host plant.
- Infection center**—A population of trees that are infected to varying degrees by a particular forest pathogen, usually a root disease pathogen or dwarf mistletoe species.
- Initial floristics**—A condition in normal plant succession where seeds or plants of later successional stages are present from the beginning following a disturbance, but are subordinate to other species for a time (see relay floristics).
- Insectivores**—Organisms that depend on insects as food.
- Instars**—With insects that undergo metamorphosis, instars indicate the juvenile developmental stages occurring between larval molts that lead to adulthood; they are often numbered, e.g., the first instar is the stage between the egg and the first larval molt.
- Interception**—The ability of plant leaves and canopies to capture and hold rain water and/or snow, allowing it to be evaporated or sublimated such that it does not reach the soil.
- Interglacial**—Pertaining to the time between episodes of glacier development, maximization, and recession.

- Interstadial**—Pertaining to a warm substage (interstade) of a glacial episode marked by a temporary retreat or stillstand of glacial ice.
- Intolerant species**—Species that do not tolerate much shade or fire (See “tolerant species”).
- Invader**—A survival strategy of plants that enables them to rapidly invade sites after fires via highly dispersive propagules.
- Invasion (plant)**—The encroachment of a plant species into a new area outside of its former range.
- Invasive**—Having a superior ability to establish in new areas by adaptive advantage, timing, or competitive ability.
- Invertebrate**—Small animals that have an exoskeleton but lack an internal skeletal framework; arthropods are invertebrates.
- Janus**—A legendary king reputed to be the first ruler of Italy; ultimately becoming the Roman god of all beginnings for whom the month of January is named. He is represented as having two faces looking in opposite directions because he could see both past and future.
- Jokulhaups**—An Icelandic term for glacial outburst floods which occur as sudden, sometimes catastrophic releases of water from a glacier or glacier-dammed lake.
- Krummholz**—The belt of discontinuous alpine forest occurring near timberline comprised of alpine species that have the genetic potential of the tree life form, but are strongly dwarfed and misshapen by the harsh environment.
- Laminae**—A set of distinct, thin layers in a stratigraphic cross section.
- Large Woody Debris (LWD)**—Any piece of woody material that intrudes into a stream channel, whose smallest diameter is > 10 cm, and whose length is > 1 m.
- Larva, pl. larvae**—A juvenile insect differing in form from the adult; examples are caterpillars, grubs, and maggots.
- Late glacial**—A northern European term for the final phase of the Pleistocene, about 13,000 to 10,200 B.P. The period was characterized by an abrupt moderation of the climate and the retreat of continental ice sheets.
- Laurentide ice sheet**—A continental ice sheet which formed in the Hudson Bay area and grew south and westward during the last part of the Pleistocene some 75,000 to 10,000 years ago.
- Lava tube**—A hollow space beneath the surface of a solidified lava flow formed when slower cooling subsurface lava withdraws from the surface crust.
- Layer**—The lifeforms (tree, shrub, or herb) that define the characteristic features of vegetation at any scale.
- Layer group**—In successional classification, layer groups are indicated by diagnostic seral indicator species occurring with 5% or greater coverage.
- Layer type**—In successional classification, layer types are indicated when a particular plant species dominates a portion of the layer group.

Leaching—Process of dissolving and moving nutrients through a soil profile such that they are inaccessible to vegetation.

Limit of stability—The balance point between assimilation and respiration of trees in a stand.

Limited-entry hunt—A hunting season in which the total number of hunters is limited by administrative rules or regulations.

Limited-entry hunting—A system of controlling hunting permits through lottery drawings.

Litter—Organic debris deposited at the forest floor; derived primarily from above-ground plant parts.

Loam—Soil material that contains 7 to 27% clay, 28 to 50% silt, and less than 52% sand.

Loess—Fine wind-deposited soil particles.

Lotic (Ecosystem or Environment)—Moving water environments, such as streams and rivers.

Low grade pathogens—Weak pathogens that are easily resisted by vigorous plants; low vigor plants are host to low-grade pathogens.

Low thinning—A commercial spacing operation conducted in overcrowded stands of trees, where the smaller trees are removed to enhance growing conditions for the larger residual trees.

Macroclimates—Regional climates.

Macropores—Large pore spaces in soil that transmit air and water to plant roots.

Maintenance respiration—Plant respiration energy needed to meet daily maintenance requirements.

Management indicator—An attribute of forest landscapes that can be quantified to simplify land management planning. Management indicators have been used to determine the success of management planning and implementation according to the apparent prosperity of the management indicator species.

Management indicator species—Any of a number of species of fish or wildlife for which a set of management guidelines have been written. Species are chosen to simplify land management planning and to aid in determining the effects of management. One type of management indicator species is the Ecological Indicator Species.

Management objective—An administratively adopted target for size or sex/age composition of a big game population.

Mantle (soil)—The earth's surface where geological and biological factors have over time created a soil mass differing from original parent materials. Soil serves as the natural medium for plant growth.

Mass wasting—Large landslump erosion events.

Matrix—The least fragmented, most continuous pattern element of a landscape; the vegetation type that is most contiguous.

Mesic—A habitat characterized by moderate moisture conditions. Drier than hydric, moister than xeric.

- Mesophytic**—Moisture loving—a plant species or community that cannot survive extreme conditions of temperature and aridity.
- Metapopulation**—A term for a population that consists of several to many sub-populations.
- Microbe**—A microscopic organism such as a bacterium, fungus, or algal species.
- Microclimate**—Climatic conditions in the immediate vicinity of a plant.
- Mid-seral forest**—See Seral Stage.
- Mineral suite**—A group of minerals that occur in close association generally representing related formations.
- Mineralizable Nitrogen**—Naturally occurring chemical compounds from which nitrogen may be liberated.
- Mixed stand**—A stand consisting of two or more tree species.
- Mollisols**—Soils with 50% or greater base saturation, usually having a surface horizon that is thick, dark-colored, with strong structure such that the soil is soft instead of hard, and massive when dry.
- Monitoring**—Actions undertaken to evaluate the efficacy and effects of any management activity on species, processes, habitats, flows, landscape and ecosystem characteristics, and outputs. Monitoring provides a feedback loop to ecosystem management experiments that addresses accountability and validity of actions.
- Morphology**—The form and structure of organisms.
- Mount Mazama**—The name given to a former volcanic mountain that erupted about 7000 B.P. (8000 tree-ring corrected years ago). Thick deposits of volcanic ash (tephra) from this eruption blanketed much of the northwestern United States. Crater Lake, Oregon, fills the caldera formed by the collapse of the mountain's top.
- mpa**—millipascal—a unit of pressure; one pascal is equal to one newton per square meter.
- Multitype species**—A wildlife species that uses two or more kinds of habitats or successional stages.
- Mycelium, pl. mycelia**—The vegetative thallus (body) of a fungus consisting of a mass of microscopic hairlike filaments (fungal hyphae).
- Mycorrhizal fungi**—Specialized fungi that form an association with plant rootlets that is mutually beneficial to the host plant and its fungus. Mycorrhizae assist in host rootlet protection against other invading pathogens, and in water and nutrient uptake.
- Mycorrhizosphere**—Soil immediately adjacent to (within 2mm) and affected by mycorrhizal fungi.
- Narrow sapwood**—A stem has narrow sapwood when less than 50% of the cross-sectional area is comprised of sapwood.
- Natural fire rotation**—A fire return interval calculated as the quotient of a time period and the proportion of a study area burned in that time period.
- Neolithic**—In archaeology, the period in human prehistory characterized by the domestication of plants and animals.

- Nitrification**—Conversion of other forms of nitrogen into nitrates. Nitrates are highly soluble in water and move easily through the soil profile and off site. Nitrates are highly available to plant roots.
- Nitrogen-fixing**—Ability of some microbes to remove nitrogen from the atmosphere and convert it to forms that are stored in soils and used by plants and microbes.
- Nitrogen-fixing plants**—Plants that are symbiotically infected by bacteria that have the capacity to fix atmospheric nitrogen. These plants are nodulated, e.g. legumes, and the bacteria responsible for fixation are contained within the nodules.
- Non-symbiotic nitrogen fixation**—Nitrogen fixation resulting from bacterial populations that do not infect plants but acquire energy to fix nitrogen from exudates of a variety of decomposing organisms, from root exudates in plant rhizospheres, or mycorrhizal exudates from mycorrhizospheres.
- Nonpoint-source pollution**—Pollution from sources that cannot be defined as discrete points, such as areas of timber harvesting, surface mining, and road construction.
- Noxious (species)**—Species that are considered undesirable because of their pernicious effects on other plant communities or habitats, or because their presence conflicts with management objectives or expectations.
- Nutrient cycles**—Characteristic nutrient flow pathways from soil or air to vegetation, and back to soil.
- Nutrient cycling**—Processes whereby elements move among animals, plants, soils, and air within and among ecosystems.
- Old growth**—Old forest often containing several canopy layers, variety in tree sizes and species, decadent old trees, standing and down dead woody material.
- Oleoresin exudation pressure (OEP)**—The positive pressure associated with oleoresin or pitch within a live coniferous tree; often used to measure of a tree's ability to resist bark beetle attack. Vigorous trees have higher OEP's and can often pitch-out attacking beetles.
- Ordinating**—The ordering or arranging of a series of things according to gradients.
- Orographic**—Pertaining to the influence of mountains; when air masses push against mountains they are lifted up as they pass over the mountains. This effect is known as orographic lifting.
- Overcrowded stands**—Stands with trees in excess of site potential. Tree vigor is poor in overcrowded stands which are more susceptible to insects, diseases, high intensity fires, and wind or snow breakage.
- Overstory**—The upper canopy layer; the plants below comprise the understory.
- Overstory removal**—Removing large trees in an overstory layer to release a lower canopy layer.
- P-group annosum**—Isolates of the root pathogen, *Heterobasidium annosum* are divided into two host specialized groups. The S-group principally attacks Spruces, hemlocks, and true firs. The P-group principally attacks Pine species.
- Paleoclimatic**—Pertaining to climates of the geologic past.

Paradigm—An operating model, pattern, or standard.

Parasite—An organism living in or on another living host organism. Parasites obtain food from their hosts, and host vitality is often compromised.

Park-like stands—Stand having scattered, large, seral overstory trees and open growing conditions usually maintained by frequent ground fires.

Partial disturbances—Disturbances that kill some patches of trees and leave others.

Parturition—Birth.

Pathogen—An entity such as a fungus, bacterium, or virus that has the capacity to incite disease in another organism (host).

Pathogenesis—The action of infecting and causing disease.

PE—See— production efficiency.

Peak flow—The greatest stream discharge recorded over a specified time period (year or season).

Percent sapwood (%SW)—Percent of stem basal area that is comprised of sapwood.

Phenology—Predetermined, climate driven, periodic, biological phenomena such as developmental phases of plants—germination, bud burst, flowering, seed drop, bud set, and dormancy.

Phenotypic plasticity—The physiological flexibility to adjust to changing environments without changing genetic constitution.

Photosynthate—The carbohydrate products formed within plants via photosynthesis.

Pile and burn—Putting logging slash into a pile by hand or machine, and burning it under controlled conditions.

Placer mining—Mining of placer deposits by washing, dredging, or hydraulic methods. Placer deposits are fluvial or glacial deposits of gravel and sand containing heavy ore minerals like gold.

Plant available water capacity—The amount of water stored in soil that can be utilized by the plant community it supports.

Plant community—A general term for an assemblage of plants living together and interacting in a specific location; no particular ecological status is implied.

Plant community type—An aggregation of all plant communities with similar structure and floristic composition. A unit of vegetation within a classification with no particular successional status implied.

Plant association—The distinctive combination of trees, shrubs, grasses, and herbs occurring in a theoretical terminal or climax community of a series of communities.

Plant series—Aggregations of plant associations having the same overstory dominant.

Pleistocene—An epoch of the Quaternary period. It began about two million years ago and ended about 10,000 years ago. Synonymous with Ice Age.

Pliocene (epoch)—The last epoch of the Tertiary period during which man and most species of modern mammals came into existence, 2 to 7 million years ago.

Plunge pool—A deep hollow scoured in a streambed at the foot of a waterfall.

Pluvial lake—A lake formed during a period of heavy rainfall; specifically a lake formed in the Pleistocene epoch during a time of glacial advance. See Pluvial Lake Lahontan and Pluvial Lake Bonneville.

Pluvial Lake Bonneville—A Pleistocene age pluvial lake which covered a vast portion of western Utah and into eastern Nevada. Great Salt Lake, Utah is the modern remnant of Lake Bonneville. See pluvial lake.

Pluvial Lake Lahontan—A Pleistocene age pluvial lake which occupied a large area of western Nevada. Modern lakes which represent remnants of Lake Lahontan include Pyramid, Humboldt, and Walker Lakes in Nevada, and Honey Lake, California. See pluvial lake.

Podzolization—Leaching of the upper layers of soil, accumulation of materials in the lower layers with the accompanying development of characteristic horizons.

Pollen counts—Method of counting and identifying pollen contained in ancient bog sediments that provides information on the vegetation existing at the time the deposit was formed.

Pollen influx—Accumulation of pollen in sediments per unit of volume or time. Absolute pollen influx is the number of pollen grains per centimeter squared per year derived from pollen concentration and rate of sedimentation.

Pollen spectra—The percentages of pollen and spores in a single pollen sample.

Pool—Portion of a stream with reduced current velocity, often with deeper water than surrounding areas, and with a smooth surface texture.

Population management unit—An administrative area in which big game populations are managed according to administrative rules and regulations, and in which population status and production are monitored.

Population viability—The likelihood of continued existence of well-distributed populations of a species.

Potamon—Fishes that live in the lower, warm water, sluggish zone of stream systems; compare with Rhithron.

Prescribed fire—Intentional use of fire by prescription to achieve specific forest and soil management objectives; under controlled conditions, the area burned, smoke emitted, and fire intensity can be controlled.

Prescribed natural fire—A fire ignited by natural processes (usually lightning) and allowed to burn within specified parameters of fuels, weather, and topography to achieve specified objectives.

Primary tephra—Said of deposits of volcanic ejecta which remain as deposited by airfall from a volcanic cloud. In cores from lakes or bogs these deposits represent volcanic ash which fell on the water surface at the time of the volcanic eruption. See redeposited tephra.

Production efficiency (PE)—Grams of biomass produced /m² of leaf area.

Progeny—Decendents or offspring.

Pruning—Mechanical removal of tree limbs of the lower stem to allow development of knot-free wood for the eventual production of clear, high-grade lumber or veneer.

Pumice—Coarse deposits of volcanic ejecta that reside near the mouth of a volcano because of their relatively large size (compared to what is usually considered ash).

Pure stand—A stand consisting primarily of one tree species.

Quaternary—A geologic period (Great Ice Age) beginning about two million years ago and extending to the present. It consists of two epochs—the Pleistocene and the Holocene.

Radiation frosts—Surface freezing due to rapid heat loss from the soil to the atmosphere.

Radiocarbon age—An age determination made of organic substances by measuring radioactive decay of ^{14}C , a radioactive isotope of carbon. See B.P. and Tree-ring corrected.

Range carrying capacity (grazing capacity)—The maximum stocking rate possible without inducing damage to vegetation or related resources.

Range condition—A generic term relating to present status of a range unit in terms of specified values or potentials.

Rate of spread (ROS)—The rate at which a fire moves across a landscape, usually measured in m sec^{-1} .

Reach—A section of stream between two specified points.

Rearing habitat—Areas required for successful survival to adulthood by young animals.

Recovery—Return of an ecosystem to a specified condition after a disturbance.

Redeposited tephra—Said of deposits of volcanic ejecta which fell out of a volcanic cloud in one setting and were later moved to another setting by earth processes. In cores from lakes or bogs these deposits represent volcanic ash usually carried into the water by surface runoff sometime after the volcanic eruption. See primary tephra.

Refugia—Isolated areas that have remained relatively unchanged (as indicated by flora and fauna) in contrast to surrounding areas which have been markedly affected by environmental changes and disturbances.

Rehabilitation (restoration)—The process of restoring sites, ecosystems, or landscapes according to essential characteristics of a former or other desired condition.

Relay floristics—Model of succession where one suite of species prepares a site for the next (like passing the baton in a relay race). See initial floristics.

Release—Liberating coniferous trees from the influence of other competing vegetation to favor growth and establishment of trees.

Relief (topographic)—The relative difference in elevation between the hilltops or mountain summits and the lowlands or valleys of a region.

Remediation—Methods to remedy, offset, cure, or minimize a problem.

Resident fish—Fish species that complete their entire life cycle in fresh water.

Resister—A survival strategy of plants that enables them to resist the harmful effects of fires through adaptations such as thick bark. Resisters survive low intensity fire with few ill effects. Ponderosa pine and western larch are resisters.

Respiration—The process in plants of breaking down carbohydrates to release energy to cells for various physiological and biochemical processes. The products of plant respiration are energy, carbon dioxide, and water.

Respiration volume—Volume of living wood expressed in m³.

Rest-rotation—A grazing system that alternates on and off years of livestock grazing on an allotment or range.

Resting habitat—Areas used by adult fish during their migration to spawning habitat.

Rhithron—Fishes that live in the upper, cold water, swift zone of stream systems; rhithron are cold water stenotherms (see Stenotherm); compare with Potamon.

Rhizomatous—Producing rhizomes, rootlike stems which grow horizontally underground, and give rise to above-ground stems and root systems.

Rhizomorph—Grouping of fungal hyphae into a root-like structure.

Rhizoplane—Root surface.

Rhizosphere—Region immediately surrounding roots (within 2mm) that is heavily influenced by root exudates, and that normally supports an active, diverse microbial population including decomposers, mycorrhizal fungi, non-symbiotic nitrogen fixers, and root pathogens.

Rhyolite—Acidic, volcanic rock.

Rhyolitic—Pertaining to rhyolite, a light colored, fine grained volcanic rock.

Riffle—Shallow section of a stream or river with rapid current and a surface broken by gravel, rubble, or boulders.

Riparian—Pertaining to land that is next to water, where plants dependent on a perpetual source of water reside.

Riparian area—Area with distinctive soils and vegetation between a stream or other body of water and the adjacent upland. It includes wetlands and those portions of floodplains and valley bottoms that support riparian vegetation.

Riparian habitat (or vegetation)—Vegetation associated with edges of streams, rivers, ponds, lakes, and other water bodies.

Riverine—All wetland and deepwater habitats contained within a natural or artificial river or stream channel, which periodically or continuously contains moving water, or which forms a link between two bodies of standing water.

Root collar—The region of the root system where roots are joined with the stem.

Root disease center—An infection center in the forest having infected, dead, and dying trees, where the causative agent is a pathogenic root-infecting fungus. Root diseases typically spread underground via fungal growth from diseased to healthy host roots.

Rotation—Refers to each generation of a managed forest; regeneration date to a final harvest date is one rotation.

Roughness—Features found in stream channels that interact with streamflow to reduce flow and/or cause channel scour. Examples include boulders, large woody debris, vegetation, and meander bends.

Rubber-tired skidders—Large, center articulated, tractor-like vehicles with round, rubber tires used for yarding logs on slopes less than 35-40%.

Run (fish)—A group of fish migrating in a river (most often on a spawning migration) that may comprise one or many stocks.

S-group annosum—Isolates of the root pathogen, *Heterobasidium annosum* are divided into two host specialized groups. The S-group principally attacks Spruces, hemlocks, and true firs. The P-group principally attacks Pine species.

Salmonids—Fish of the family Salmonidae, including salmon, trout, chars, whitefish, ciscoes, and grayling. In general usage, the term often refers to salmon, trout, and chars.

Salvage—The cutting of dead, dying, or deteriorating trees before they lose their commercial value.

Sanitation-salvage—A type of tree harvesting where individual trees are removed that have been, or are in imminent danger of being killed or damaged by forest pathogens or insects; the method is often used to minimize spread to healthy trees.

Sap rot—Said of recently killed trees or those with partial stem damage. Sap rot is that decay occurring exclusively in sapwood.

Sapwood—The sapwood is the wood residing between the inner bark and the heartwood that is responsible for the translocation of water and nutrients to foliage when trees are alive.

Scalping—The physical removal of surface soil horizons and ground vegetation to facilitate hand planting and to reduce competition for limited site resources during the establishment period.

Scarification—Physical disturbance of surface soil horizons, usually to improve germination and early survival of natural regeneration.

Scour—Local removal of material from streambeds by flowing water.

Sediment—Material carried in suspension by water, which will eventually settle to the bottom.

Seed tree harvesting—A method of clearcut harvesting where all commercial trees are removed except a few which are left to provide seeds to regenerate the new stand.

Selection systems—Uneven-aged harvesting systems.

Senescence—The plant growth phase that begins at full maturity and ends at death, characterized by declining physiological function.

Seral—1. Successional; 2. A species or a community which will be replaced by another in succession.

Seral species—Plant species of early, middle, and late successional plant communities of any plant association. Often used in a more limiting sense to speak of the dominant conifer vegetation that follows major disturbance episodes.

Seral stage—Any of a predictable sequence of transitional plant communities that leads to the terminal or climax community.

Sere—The entire set of all developmental phases of a forest stand; each developmental phase is a seral stage (see Seral Stage).

Series—An aggregation of taxonomically related associations that takes the name of the climax species that dominates the principal layer. A taxonomic unit in a classification.

Serotinous cones—Conifer cones whose scales are sealed with a droplet of pitch. Cones usually open and release their seeds only when exposed to intense heat.

Shelterwood harvesting—A method of clearcut harvesting where all commercial trees are removed except those that are left to provide seeds to regenerate the new stand, and to protect the young regenerating stand from extremes of heat and cold. After the new age class has been established, this overwood is often removed.

Siltation—Adding sediment to streams and reservoirs.

Silvicultural systems—For this report, silvicultural systems, harvesting systems, and regeneration systems will be used interchangeably, since silvicultural systems and harvest systems are named after their regeneration method.

Silviculture—The practice of manipulating stand structure and composition to achieve the objectives of the landowner.

Slash—Harvest residues—usually limbs, foliage, and small logs—remaining after tree stems have been yarded during harvesting.

Slump-earth flow—Movement of large, unstable earth masses.

Slump (soil)—The downward slipping of a mass of rock or soil moving as a unit or as several subsidiary units, usually with backward rotation on a more or less horizontal axis parallel to the cliff or slope from which it descends.

Smolt—Juvenile salmonid one or more years old that has undergone physiological changes to cope with a marine environment; the seaward migrant stage of an anadromous salmonid.

Soil-borne pathogens—Plant pathogens that occur naturally in soil.

Soil fauna—Usually refers to small animals contained in soil; arthropods.

Soil flora—Refers to small plants (fungi, bacteria, algae, lichens) that occur in soil.

Soil nutrient profile—Distribution of nutrients in soil by depth and horizon.

Soil organic matter—Includes all soil organic components (litter, humus, wood...)

- Soil structure**—Refers to the physical structure of soils that facilitates air and water movement or storage.
- Soil wood**—Decayed wood buried in soil profiles.
- Spawning gravel**—Sorted, clean gravel patches of a size appropriate for the needs of resident or anadromous fish.
- Spawning habitat**—Areas used for spawning by adult fish.
- Species-habitat matrix (or matrices)**—A table or data base that estimates the relative suitability of vegetation associations and seral stages for meeting various life needs of wildlife species.
- Splash dam**—A makeshift dam used to temporarily accumulate logs and water before floating them downstream for processing.
- Split-season hunt**—A hunting season that is partitioned into two or more segments. Hunters are normally allowed to hunt in only one segment.
- Spore**—A microscopic reproductive propagule of fungi analogous to the seed of green plants.
- Sporulate**—To produce spores.
- Spotting**—Mass transfer of firebrands ahead of a fire front.
- Stand**—Vegetation occupying a specific area and sufficiently uniform in composition, size, arrangement, structure, and condition as to be distinguished from the vegetation in adjoining areas.
- Stand initiation**—Following a recent disturbance, a new stand is initiated when trees, shrubs, and other species actively colonize the disturbed area.
- Stand replacing disturbances**—Disturbances which remove or destroy all trees previously existing in a stand.
- Steady state**—An equilibrated or stable condition of certain ecosystem processes.
- Stem exclusion**—The condition several decades after a disturbance when established trees have grown large enough to effectively exclude smaller trees and other vegetation, and to minimize new ingrowth.
- Stenotherm**—Fishes with very narrow physiological tolerances that require the highest quality water.
- Steppe**—Grassland vegetation occurring where the climate is too dry to support tree growth.
- Stock**—Group of fish that is genetically self-sustaining and isolated geographically or temporally during reproduction.
- Stocking**—Refers to the numbers of tree stems in a given area. Tree density is also implied.
- Stomates**—Breathing and transpiration apertures of plant leaves; many plants control opening and closure.
- Stratigraphic position**—Refers to the dating of a particular layer in a sequence of sedimentary deposits according to the relative order in which all the layers making up the sequence were deposited. Generally this means that any given layer is considered older than layers above it and younger than layers below it.

Stratum—A canopy layer of trees.

Stream reach—Section of stream between two specified points.

Streamflow (discharge; instream flow)—A measure of the volume of water flowing past a reference point per unit time (e.g., m³/sec).

Structure—The physical organization and arrangement of vegetation; the size and arrangement (both vertical and horizontal) of trees and tree parts.

Sub-watershed—Portions of watersheds (see Watershed) defined for management purposes; in the Blue Mountains of eastern Washington and Oregon, sub-watersheds typically range in size from 1,000 to 10,000 acres.

Substrate—The material forming the underlying layer of streams. Substrates may be bedrock, gravel, sand, clay, boulders, etc.

Succession (ecological succession)—An orderly process of biotic community development that involves changes in species, structures, and community processes over time; it is reasonably directional and, therefore, predictable.

Succession (primary)—Succession occurring in areas that have been catastrophically disturbed and existing biotic communities have been destroyed.

Succession (secondary)—Succession occurring in areas that have been disturbed and existing biotic communities have been merely disrupted.

Successional pathway—The probable course of community development within a defined framework of seral stages for a particular disturbance regime.

Successional stage—See Seral stage.

Surface fire—A fire burning along the surface without significant movement into the understory or overstory, usually below 1 m flame length.

Sustainable harvestable surplus—See Harvestable Surplus.

Symbionts—Partners in a relationship of mutual benefit.

Symbiotic N-fixers—Bacterial symbionts that invade plant roots, form nodules, and supply nitrogen to the host plant.

Tephra—A term for wind transported volcanic ejecta.

Tephrochronology—The dating of layers of volcanic ash in order to establish a sequence of geologic or archaeological events. This is possible because the tephra produced during any given eruption often have unique physical and chemical properties which allow the correlation between an ash deposit and the eruption which formed it.

Ternary plots—A triangular diagram that graphically depicts the composition of a three part mixture.

Terrestrial—Pertaining to the land.

Texture (soil)—The ratios of silt, clay, and sand in soils.

Thermal contact coefficients—The products of thermal conductivity and heat capacity by volume.

Thermal conductivity—The rate at which one calorie of heat is conducted through one centimeter of soil under a constant temperature difference of 1°C.

Thermal diffusivities—The thermal conductivity divided by the heat capacity by volume.

Thinning—The planned removal of trees during the development of a forest, used to regulate characteristics of tree growth through adjustments in tree spacing and density without creating a new age class.

Till—Unsorted boulders, gravel, sand, silt, and clay deposited by glaciers without redistribution or sorting by melt water.

Tiller—A sprout or branch which grows from the base of a plant, especially those of the grass family.

Timelag class—A method of classifying fuels according to the rate at which they gain or lose moisture, indexed by fuel size class.

Tolerant (shade)—Any of a number of physiological characteristics that enable a plant species to develop and grow in the shade of other plants.

Transpiration—See Evapotranspiration.

Tree-ring age—An age determination made on wood based on the counting and correlation of annual growth ring patterns (dendrochronology). The method includes the cross-dating of living and fossil trees of overlapping ages such that the sequence of growth patterns for a region may extend into the distant past.

Tree-ring corrected—The radiocarbon dating method assumes a constant rate of atmospheric carbon isotope production and decay. This assumption, however, does not hold. Therefore, radiocarbon ages cannot be directly converted into calendar years. To overcome this, values for radiocarbon-dated tree-rings of known age are applied to correct radiocarbon dates to actual calendar ages. Differences between a radiocarbon and a tree-ring age can be significant. For instance, the radiocarbon age for the eruption of Mt. Mazama is about 7000 B.P., but the tree-ring corrected age is closer to 8000 years ago.

Tree improvement—Genetically breeding trees for a desired set of heritable characteristics.

Trend—The direction of change in ecological status or resource value rating observed over time.

Typic Vitrandepts—Soils with large amounts of ash and pumice and very low amounts of their weathering products.

Umbrella species—A large-bodied, popular species having a large home range and broad requirements for habitats and resources, that can be managed so as to also provide habitats and resources for other species; similar to Flagship Species.

Unconstrained—Having a wide valley floor, generally greater than two active stream channel widths, with extensive floodplain surfaces. The stream is free to meander and form a complex channel.

Underburn—Burn by a surface fire.

Understory—Collectively, those plants that are beneath the overstory. See Overstory.

Understory fire—A fire that burns in the understory, more intense than a surface fire with flame lengths of 1-3 m.

Understory reinitiation—The stand development phase following stem exclusion when declining overstory density and cover has enabled initiation of new understory vegetation.

Uneven-aged systems—Harvest systems that create multiple age classes of trees. Harvest entries are partial removal entries. Uneven-aged systems include selection and partial cut systems.

Ungulates—Cloven hoofed animals.

Unitype species—A wildlife species that presumably requires one kind of habitat or successional stage. Unitype species typically prefer interior, more secluded portions of their habitats.

Upland—The portion of a landscape above the valley floor.

Vegetation zone—A land area with a single overstory dominant as the primary climax dominant. Occasionally zones are named after major seral species. Other climax types may exist in the zone.

Vegetative composition—The plant species present in a plant community.

Viability—See Population Viability.

Volcanic ash—Fine grained (as opposed to coarse grained pumice) volcanic deposits having the appearance of glass shards.

Water use efficiency (WUE)—Grams of biomass produced/gram of water transpired.

Water-holding capacity—The amount of water a soil can hold over an extended period without gravity induced loss.

Water-repellant layers—Layers of soil that are resistant to water penetration, characteristic of intensely burned soils; possibly occurring as a result of condensation of volatilized organic matter on soil particles.

Water repellency—The resistance of soil to wetting, which can be increased by intense fires.

Watershed (also catchment area; basin; drainage area)—Total land area draining to any point in a stream, as measured on a map, aerial photo, or other horizontal, two-dimensional projection.

Wide sapwood—A stem has wide sapwood when more than 50% of the cross-sectional area is comprised of sapwood.

Wildfire—A human or naturally-caused fire that does not meet land management objectives.

Windthrow—Trees blown over by the wind.

Woodland—Vegetation characterized by a rather closed stands of trees of short stature.

Woody residue—Woody plant products, (logs, stems, boles, large branches) derived from normal mortality, harvesting, windstorms, insect and disease outbreaks, other disturbances; occurring on or suspended above the soil surface.

WUE—See—water use efficiency.

Xeric—Pertaining to very dry moisture conditions; drier than mesic.

Xerothermic—Dry and warm periods of the recent past; plants adapted to dry/warm conditions.

Yard—Moving cut trees or logs to a centralized landing for transport to mills and other processing facilities.

Young-seral Forest—See Seral Stage.

Younger dryas—A European term used for an interval of late Glacial time (about 10,000-11,000 B.P.) during which the climate cooled, favoring reexpansion or slowing of retreating glaciers. This event may be recognized throughout the northern hemisphere.

Zone—A geographic area of uniform macroclimate where climatic climax associations share the same characteristic species of the principal layer.

Zoogeography—The study of evolutionary history and prehistoric and current distributions of animals.

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